AD-A049 859 ROCKWELL INTERNATIONAL LOS ANGELES CALIF LOS ANGELE--ETC F/G 20/6
FIBER OPTICS COST ANALYSIS PROGRAM (FOCAP).(U)
SEP 77 C C ZELON, J E CASSIDY, R G SHIPLEY F33615-76-C-1260
UNCLASSIFIED NA-77-729 AFAL-TR-77-190 NL

1 OF 3

ADA049 859

AFAL-TR-77-190

2

AD-A049859

FIBER OPTICS COST ANALYSIS PROGRAM (FOCAP)

Rockwell International Corporation
Los Angeles Division
International Airport
Los Angeles, CA 90009

September 1977

Technical Report AFAL-TR-77-190

Final Report for Period June 1976 – September 1977

Approved for public release; distribution unlimited.

Prepared for
AIR FORCE AVIONICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

NOTICE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER AFAL-TR-77-190	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) FIBER OPTICS COST ANALYSIS PROGRAM (FOCAP)		5. TYPE OF REPORT & PERIOD COVERED Final Technical Report June 1976 to September 1977
		6. PERFORMING ORG. REPORT NUMBER NA-77-729
7. AUTHOR(s) C. C. Zelon, J. E. Cassidy, R. G. Shipley		8. CONTRACT OR GRANT NUMBER(s) F33615-76-C-1260
9. PERFORMING ORGANIZATION NAME AND ADDRESS Rockwell International Corporation Los Angeles Division International Airport, Los Angeles, CA 90009		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2003-07-16
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Avionics Laboratory (AFAL/AAT) Air Force Systems Command Wright-Patterson Air Force Base, Ohio 45433		12. REPORT DATE September 1977
		13. NUMBER OF PAGES 253
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

fiber optics, aircraft internal data transfer, life cycle cost, multiplexing, avionics, electronic interface adaptation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The significance of this research and development to the Air Force is that it establishes methods for comparing the life cycle cost of fiber optics and wire data transfer systems on large military aircraft, and uses those methods to perform cost analyses on the data transfer subsystems. Using the B-1 as an example, the applicability of fiber optics to the B-1 avionics/electrical systems was identified. Conceptual fiber optics data transfer systems were designed. The present wire and the conceptual fiber optics designs formed a

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract (Continued)

basis for computerized life cycle cost comparisons. Sensitivity analyses and cost trade-offs were performed to determine cost drivers in the application of fiber optics.

Results show significant cost benefits can be gained by the implementation of fiber optics in data transfer subsystems having data rates in excess of 2 to 3 megabits per second.

PREFACE

This report documents the methods used and the results of the Fiber Optics Cost Analysis Program (FOCAP), U.S. Air Force Contract F33615-76-C-1260, project 2003-07-16. The study was performed by the Los Angeles Division (LAD), a division of Rockwell International Corporation. The program was administered by the Air Force Avionics Laboratory (AFAL), Wright-Patterson Air Force Base, Ohio. The Air Force Project Engineer directing the study was Mr. Kenneth Trumble, AFAL/AAT.

The studies described in this report were performed from 30 June 1976 to 30 June 1977. The draft final report was submitted for approval on 22 July 1977. Program manager was C. C. Zelon. The principal investigators were R. G. Shipley (design studies) and J. E. Cassidy (cost analysis), with major contributions from E. A. Dahlke, K. R. Hall, R. Hurst, F. C. Lee, and L. M. Roark.

The cost data shown in this report do not constitute a commitment on the part of Rockwell. They are for comparative purposes only.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure	Title	Page
32	DSG, Effect of Cost of Wire and Fiber Optic Cable on LCC Savings	144
33	EMUX - Effect of Cost of Fiber Optic Cable on LCC Savings	146
34	DSG - Effect of Fiber Cable Preparation and Installation Time on LCC Savings	147
35	Super-MUX - Effect of Computer Cost and Reliability on LCC Savings	148
36	DSG - Effect of Weight Reduction on LCC Savings	149
37	Effect of Weight Reduction on LCC Savings for a "Rubber" Aircraft	150
38	DSG - LCC Savings Versus ΔLRU Cost	151
39	Impact of Wire Segment MTBF on LCC (FY 1977 $ Millions)	154
40	Impact of Wire Segment MTTR on LCC (FY 1977 $ Millions)	155
41	Bandwidth Cost Trade-Off	159
42	Bandwidth/Weight Trade-Off	161
43	Cost Drivers for Candidate Fiber Optic Subsystems	169
B-1	Recovery From Transient Nuclear Radiation for Plastic Clad, Pure Fused Silica Fiber.	203
B-2	The Effects of Temperature on the Maximum Value of Pulse-Induced, Transient Absorption (Peak Transient Absorption)	204
B-3	Recovery of Transient Absorption in Schott Vitreous Silica Fibers	205
B-4	Recovery of Absorption Versus Time for Corning Low-Loss (Type B) Fibers	206
B-5	Polystyrene Fiber Nuclear Response	208
B-6	PIN Diode Characteristic Response to Permanent Radiation Damage Effects	210
B-7	UN4001 PIN Diode Gamma Response	211
B-8	MA47084 PIN Diode Gamma Response	212
B-9	PIN 3D PIN Diode Gamma Response	213
B-10	MRD500 PIN Diode Gamma Response	215
C-1	Type A, Single-Channel EOAU	218
C-2	Type B, Dual-Channel EOAU	219
C-3	Type C, Unipolar EOAU	220

Figure	Title	Page

LIST OF TABLES

Section I

INTRODUCTION

Recent advancements in fiber optics technology, both in the quality of components and reduction in costs, make fiber optics data transfer systems an attractive alternative for replacing currently used wire systems on military aircraft. Fiber cables have the capability of transmitting data at a higher rate than conventional wires. In modern military aircraft with sophisticated avionics, the large bandwidth capability of fibers can often allow replacement of multiple wires with a single-fiber cable, thus reducing the weight and volume of the transmission system. The fibers, being dieletric in nature, are both noninductive and nonconductive. Thus, the employment of fiber optics cables offers the additional benefit of reduced electromagnetic susceptibility and the potential for the reduction of conduits, filtering networks, and shielding.

The isolation between fiber optics links is also by far superior to wire, because the cladding and the jacket of the fibers provide an inherent light shield, and there is no crosstalk and no coupling between adjacent lines.

Since electrical energy is not being transmitted via fibers, there are no spark or fire hazards and the air vehicle safety is increased. Should a fiber optics cable become damaged, no shorts will occur and there will be no damage to associated equipment. Fiber links can be routed in the vicinity of ammunition, fuel, or propellants. This can often save many feet of cabling and simplify installation and routing.

The FOCAP study was initiated to (1) quantitatively examine in detail the economic trade-offs associated with various fiber optic system approaches that satisfy internal aircraft data requirements, (2) compare these results with the costs associated with currently used wire data transfer systems, and (3) identify cost-effective applications of fiber optics technology.

Section II

SUMMARY

The FOCAP study addressed the problem of comparing the total cost of a large aircraft system equipped with conventional wire to that of one equipped with fiber optics data transfer systems. The B-1, having numerous avionics and electronics subsystems, was selected as the basis for the study. The life cycle cost (LCC) was used for cost comparisons. The LCC includes the research, development, test, and evaluation (RDT&E) costs, acquisition costs, and operation and support (O&S) costs.

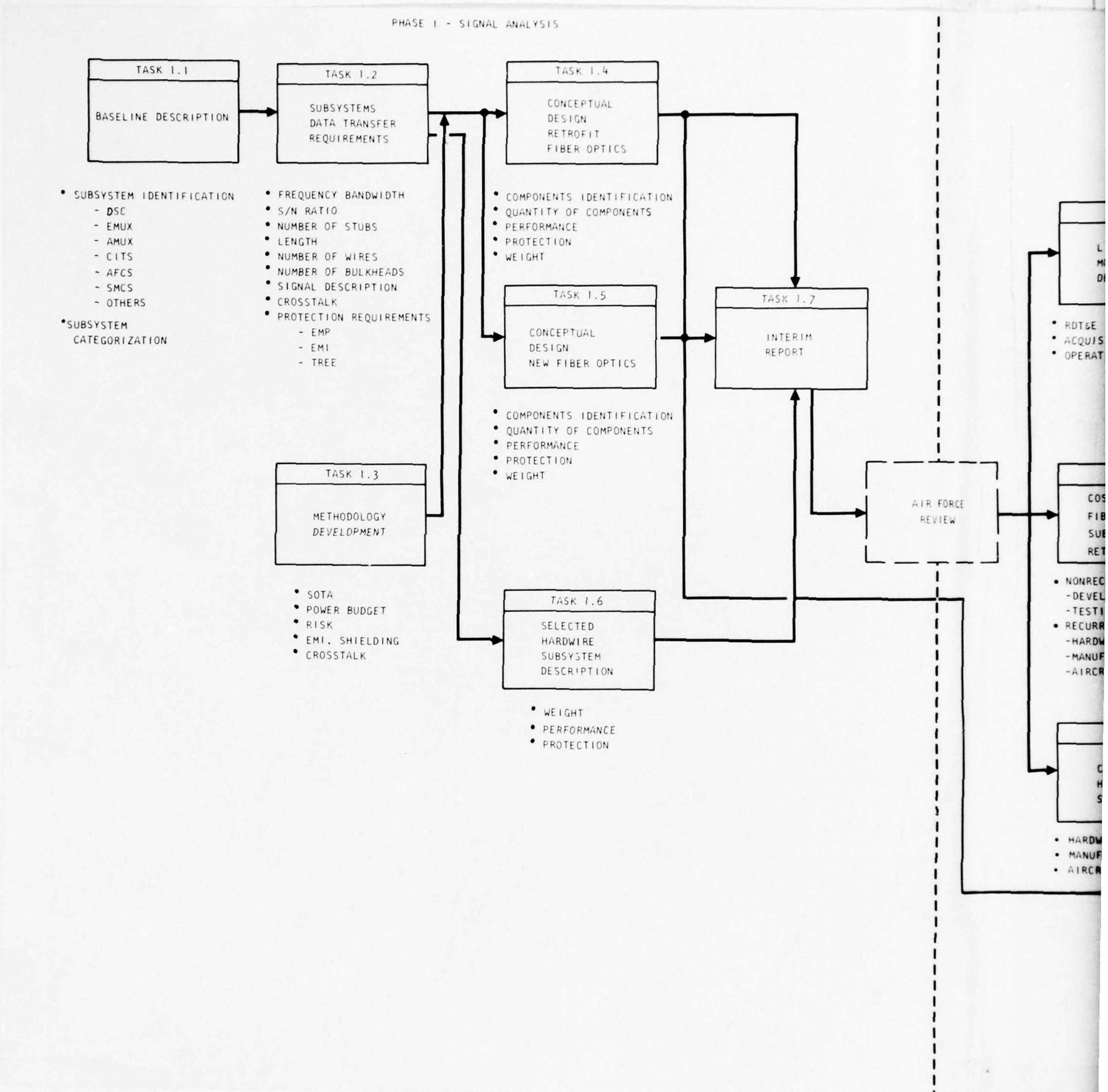
The study was divided into two phases: phase I, signal analysis, and phase II, cost analysis. A total of 21 tasks were identified, as shown in the task flow diagram (Figure 1).

In phase I, the data transfer requirements associated with the B-1 avionics and electronics subsystems were identified and the applicability of fiber optics to these requirements was analyzed. A total of 12 subsystems were selected as candidates for fiber optics implementation. Three of the 12 subsystems are multiterminal 1 megabit/second (mb/sec) multiplex systems. A fourth, the Defensive Subsystem Group (DSG), requires parallel multiterminal digital transmission at rates up to 40 mb/sec. The remaining eight subsystems process signals consisting of ac and dc analog, discretes, and digital.

Data transfer requirements and detailed block diagrams for the selected subsystems were developed. The block diagrams identified the number of wire segments, bulkhead connectors, wires, conduits, and overbraid footage, and the number and location of line replaceable units (LRU's).

The availability and performance of fiber optics components, as well as their compatibility with the B-1 environment (thermal, vibration, nuclear), were studied. Suitable components were then selected. Calculations were performed to assure that the projected power budgets resulted in satisfactory signal-to-noise ratios and achieved the required bit error rates. Fiber optics configurations were derived, and installation block diagrams showing fiber cable routing and length, number, and location of connectors and couplers were made (Reference 1).

Both new designs and retrofit fiber optics designs were derived. The retrofit concept is an "add-on" modification in which subsystem wiring is typically replaced by fiber cables and electro-optical conversion units added to the existing LRU's. In the new design concept, present LRU's are redesigned to have their input/output sections accommodate a multiplexed fiber optics data transfer capability.


PHASE I - SIGNAL ANALYSIS
TASK 1.1
BASELINE DESCRIPTION
• SUBSYSTEM IDENTIFICATION
- DSC
- EMUX
- AMUX
- CITS
- AFCS
- SMCS
- OTHERS
• SUBSYSTEM CATEGORIZATION
TASK 1.2
SUBSYSTEMS DATA TRANSFER REQUIREMENTS
• FREQUENCY BANDWIDTH
• S/N RATIO
• NUMBER OF STUBS
• LENGTH
• NUMBER OF WIRES
• NUMBER OF BULKHEADS
• SIGNAL DESCRIPTION
• CROSSTALK
• PROTECTION REQUIREMENTS
- EMP
- EMI
- TREE
TASK 1.3
METHODOLOGY DEVELOPMENT
• SOTA
• POWER BUDGET
• RISK
• EMI, SHIELDING
• CROSSTALK
TASK 1.4
CONCEPTUAL DESIGN RETROFIT FIBER OPTICS
• COMPONENTS IDENTIFICATION
• QUANTITY OF COMPONENTS
• PERFORMANCE
• PROTECTION
• WEIGHT
TASK 1.5
CONCEPTUAL DESIGN NEW FIBER OPTICS
• COMPONENTS IDENTIFICATION
• QUANTITY OF COMPONENTS
• PERFORMANCE
• PROTECTION
• WEIGHT
TASK 1.6
SELECTED HARDWIRE SUBSYSTEM DESCRIPTION
• WEIGHT
• PERFORMANCE
• PROTECTION
TASK 1.7
INTERIM REPORT
AIR FORCE REVIEW

1

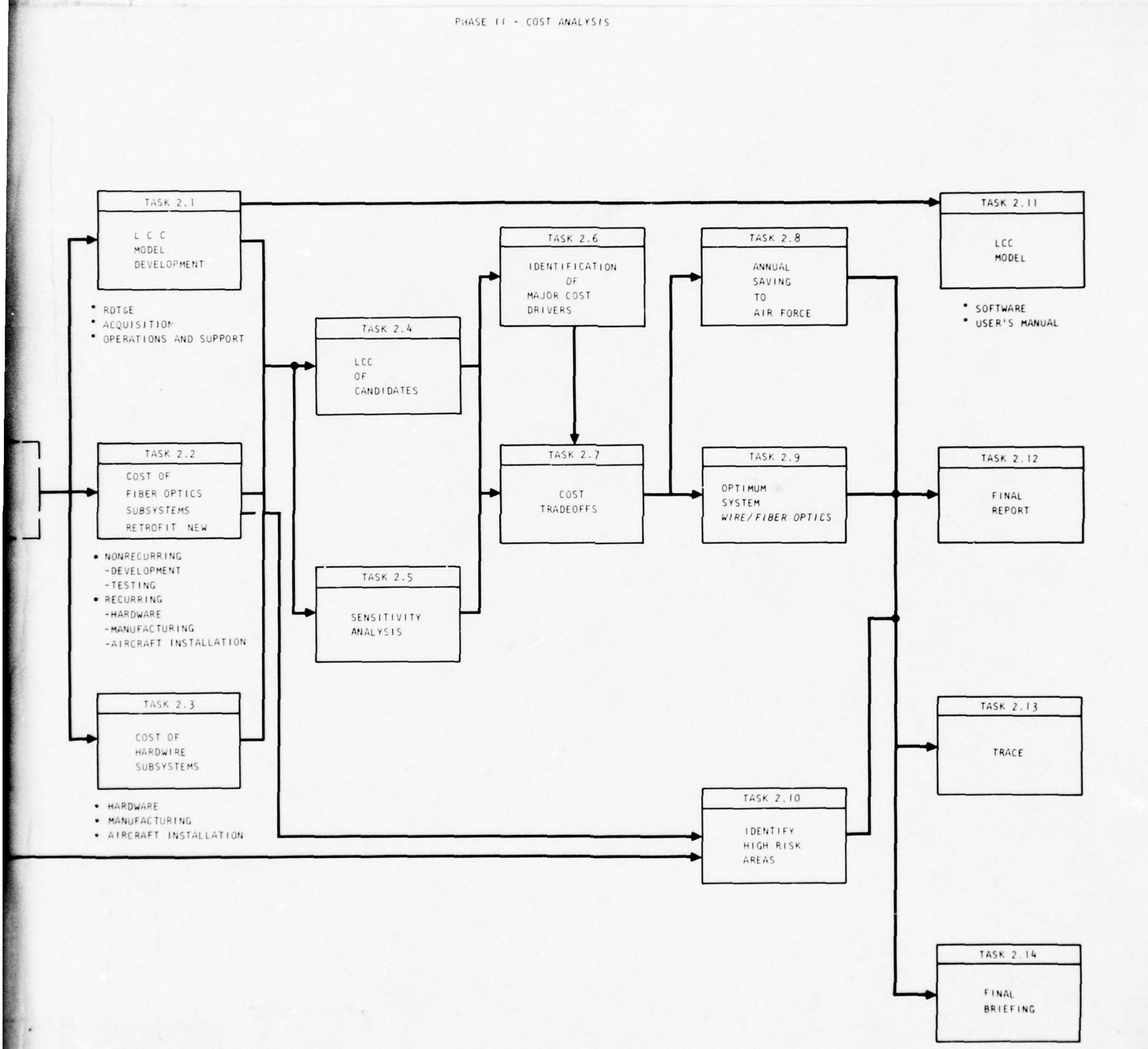


Figure 1. FOCAP task flow diagram.

2

Two new multiplexing concepts were conceived to exploit the high data rate capability of fiber optics. One of the new multiplexing concepts (8-MUX) combined eight subsystems, and the other (Super-MUX) combined 11 subsystems.

Substitution of fiber optics into the 40 mb/sec system resulted in 94-percent segment count reduction, 91-percent cable length reduction, and 86-percent weight reduction. The installation comparison for this subsystem is shown in Table 1.

The Super-MUX concept resulted in 16-percent segment count reduction, 39-percent cable length reduction, and 16-percent weight reduction as shown in Table 2. The function of 36 present LRU's were combined, resulting in 25-percent reduction inthe number of LRU's.

Installation parameters for the 1 mb/sec multiplex systems were not appreciably affected by the substitution of fiber optics.

A weight comparison for the B-1 systems is shown in Figure 2. No appreciable weight difference was found for the 1 mb/sec system. A saving of 380 pounds can be realized in the 40 mb/sec system. A total weight saving of 600 pounds can be accomplished if fiber optics are implemented in the 40 mb/sec system and in the Super-MUX.

In phase II, the Data Transfer Life Cycle Cost (DTLCC) computer model was derived and used to determine the total aircraft cost as a function of the design and cost parameters of the respective data transfer subsystems.

TABLE 1. INSTALLATION COMPARISON - 40 MB/SEC SUBSYSTEM

	Wire	Fibers	% Reduction
No. of segments	7,225	390	94.6
No. of terminations	14,450	780	94.6
No. of bulkhead connectors	22	14	36.3
Cable length (ft)	79,600	6,800	91.4
Conduit Length (ft)	220	-	100
Overbraid length (ft)	365	-	100
Weight (lb)	442.1	61.5	86.0

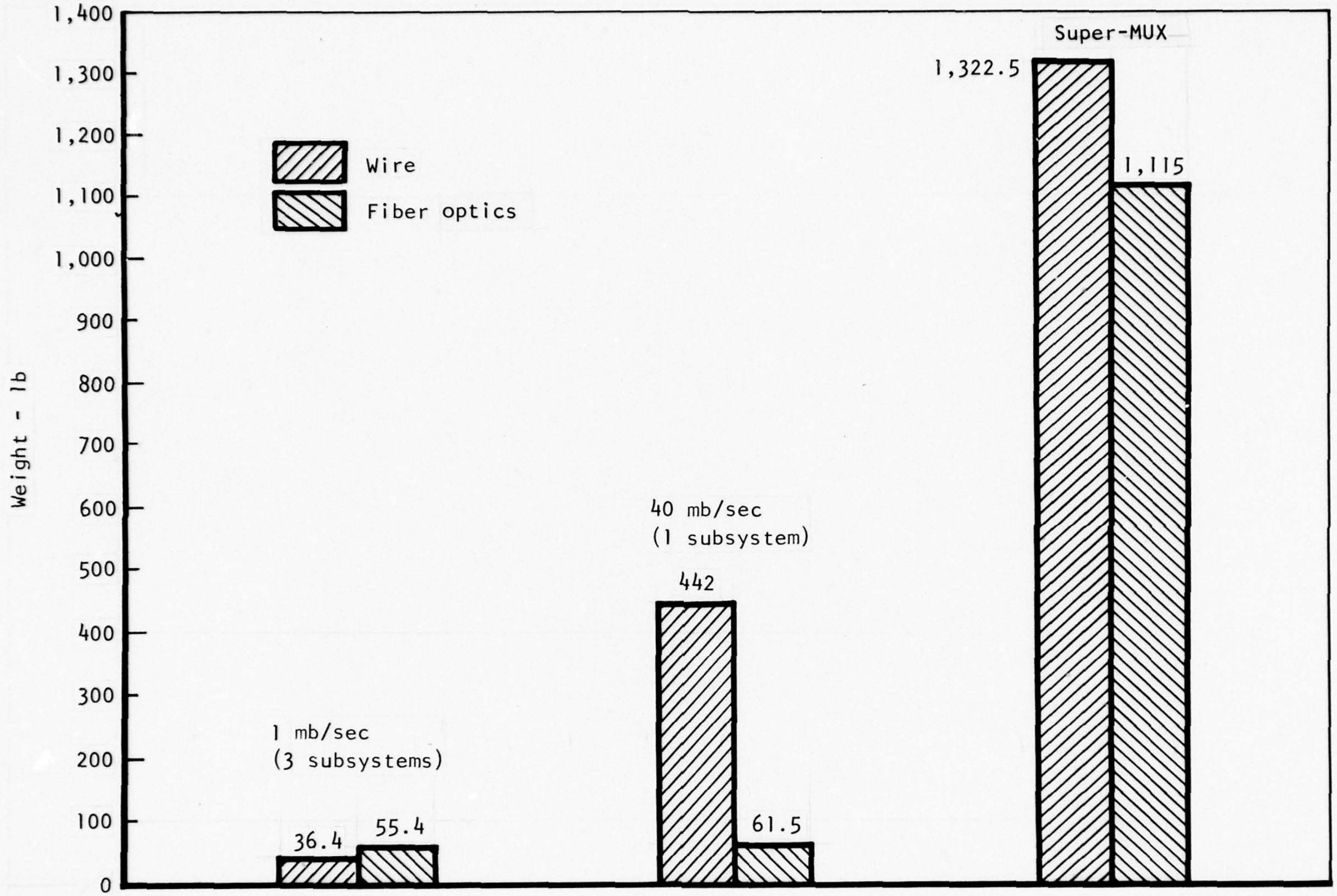


Figure 2. Weight comparison.

TABLE 2. INSTALLATION COMPARISON - SUPER-MUX

Parameter	Wire	Fiber Optics	
		Wire	Fibers
No. of segments	12,455	10,400	76
No. of terminations	24,910	20,800	152
Cable length (ft)	63,150	37,800	882
No. of bulkhead connectors	13	2	2
Conduit length (ft)	206	94	-
Overbraid length (ft)	353	157	-
No. of LRU's	36	27	
Weight (lb)	1,323	1,110	

LCC was divided into three categories:

1. Research, development, test, and evaluation (RDT&E)

2. Acquisition

3. Peacetime operations and support (O&S)

Cost elements, including component and material procurement, manufacturing labor, initial spares, recurring spares, and corrective maintenance labor, were identified, and cost-estimating equations were derived.

The cascading effects of weight changes were assessed in two ways: (1) for an aircraft whose size and shape is fixed (i.e., the B-1), and (2) for a "rubber" (or conceptual) aircraft that is allowed to shrink and grow according to the weight changes while holding performance constant. The cost payoff was determined to be \$118 per pound for the fixed-size aircraft and \$1,127 per pound for the rubber aircraft. The cost payoff for the fixed-size aircraft reflects the reduction in operation and support costs due to reduced fuel consumption and tanker support. The "rubber" aircraft cost factor was derived from parametric vehicle sizing and cost models.

Results indicate that fleet LCC savings of \$300 million can be obtained by substituting fibers in the 40 mb/sec DSG system and by incorporating a Super-MUX system in the fixed-size B-1. This \$300 million saving in 1977 dollars increases to about \$500 million when the effects of inflation are considered (then-year dollars). Implementation of fiber optics in the early conceptual stages of a large-aircraft design can result in saving an additional 50 percent. Figure 3 shows those LCC savings for the B-1 and rubber aircraft. There is no appreciable savings when fiber optics are substituted for wire in low-data rate (1 mb/sec) multiplex systems.

Sensitivity analyses and cost trade-offs were performed to determine major cost drivers in the application of fiber optics for data transmission. The B-1 LCC savings for the 40 mb/sec system were achieved primarily by the reduction in the number of cable segments and by the reduction in weight. The major cost categories that contributed to this saving prioritized in order of their contributions were:

- Cable maintenance
- Segment preparation and installation
- Fuel and tanker support (due to weight savings)
- Cable procurement

For the rubber aircraft, the reduction due to weight was predominant, since the weight savings were allowed to cascade throughout the total aircraft.

The study shows that, when a new major multiplexing concept such as the Super-MUX is created, the LCC savings are due to multiplexing systems previously not multiplexed, consolidation of existing multiplex systems (causing reduction in procurement and maintenance costs), and the associated reduction in weight. Those items override the cost of fiber optics components and therefore are a dominant factor in the LCC of such a configuration.

The study concludes that for future sophisticated military aircraft with higher data rates, the LCC savings could be significantly larger than those projected for the B-1.

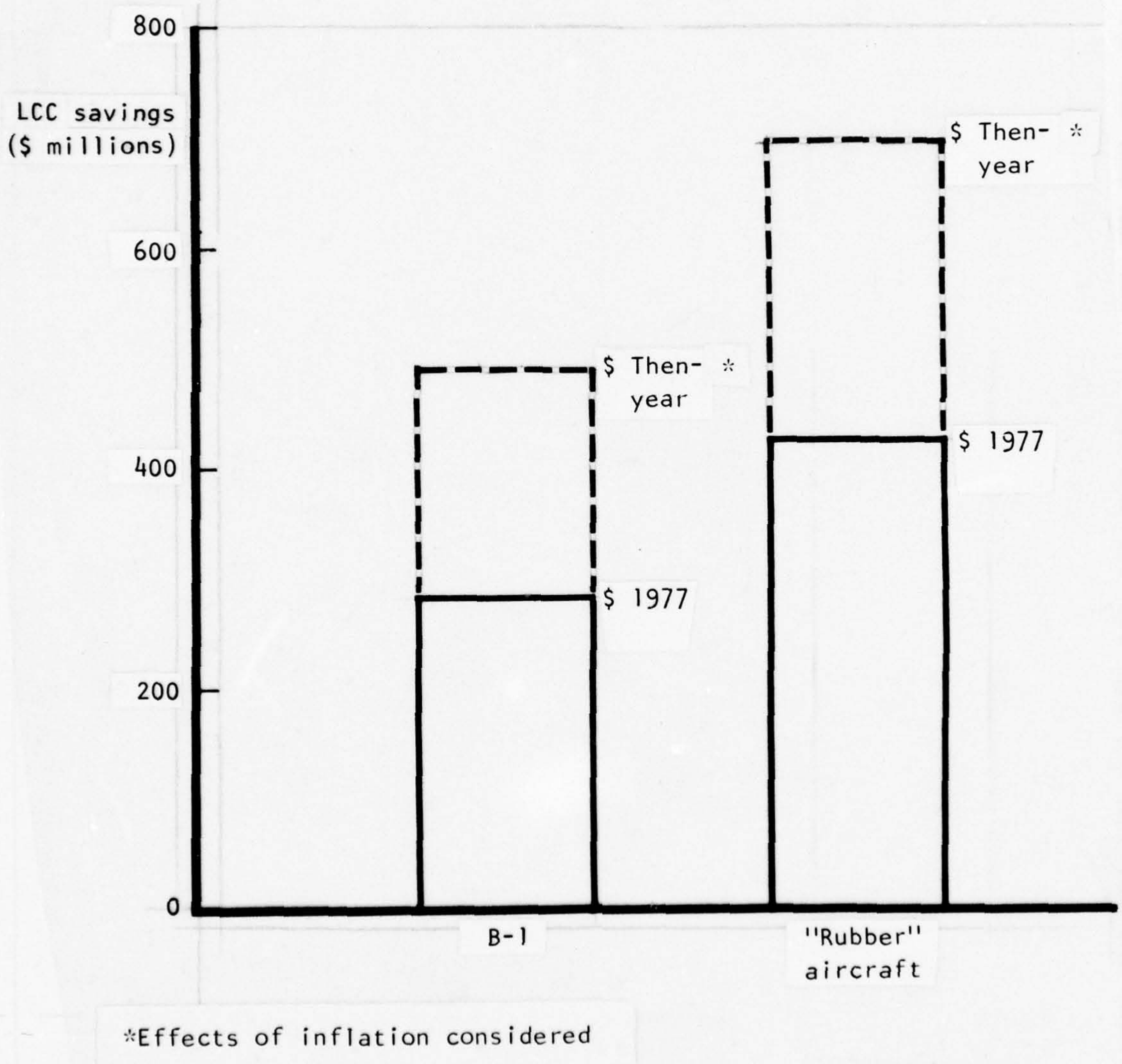


Figure 3. Potential LCC savings due to fiber optics
(DSG and Super-MUX).

Section III

DESIGN STUDIES

BACKGROUND

Phase I of the Fiber Optics Cost Analysis Program (FOCAP) study was devoted to describing existing wire data transfer subsystems and deriving conceptual fiber optics subsystems in sufficient detail for cost analyses to be performed. The wire and conceptual fiber optics designs form a basis for life cycle cost analysis of fiber optics data transmission subsystems.

The FOCAP study uses the B-1 aircraft, which has a large variety of avionics subsystems, as its basis for analysis.

Ground rules employed in phase I of FOCAP include:

1. "Retrofit" and "New Design" Definition. A retrofit fiber-optics subsystem is implemented with minimum practical impact to the present aircraft configuration. Typically, this is an "add-on" installation concept in which subsystem wiring is replaced by fiber cables and electro-optical conversion and/or multiplexing units are added to the present line replaceable unit (LRU) outputs. A new design implementation makes use of any feasible fiber optics advantage. A subsystem may be completely redesigned or an LRU may have its output section designed to accommodate a multiplexed fiber optics data transfer capability and data transferred over interconnecting fiber cables.

2. Performance of Fiber Optics Subsystems. The performance of all (retrofit and new design) fiber optics subsystems must be at least as good as that of wire subsystems.

3. Retrofit Adapter Units. The conceptual design of retrofit fiber optics subsystems is aimed at internal modification of present LRU's. External interface adapter units are considered only if obvious advantages are identified.

4. Technology Base. The 1977 fiber optics technology base and the 1979-80 aircraft implementation time are assumed.

STUDY BASELINE

The B-1 is a large, modern military aircraft carrying a variety of sophisticated avionics subsystems. A total of 12 subsystems on the B-1 were identified as candidates for fiber optics implementation. Noncandidate

wiring links such as power lines were screened from aircraft integrated schematics, and block diagrams for the remainder of the subsystem wiring were drawn. These block diagrams show the location of LRU's, the bulkhead connectors, the wire routing, the wire segments, the length and number of wires. Three of the 12 subsystems (the automatic flight control subsystem, the structural mode control subsystem, and the manual flight controls) were combined into a single block diagram, thus resulting in 10 wiring block diagrams. The description of those subsystems is contained in this section. All wiring block diagrams are contained in Reference 1. The following paragraphs contain a description of the major subsystems, and describe the methods used and results obtained in the process of defining a group of baseline wire subsystems to be used in the FOCAP study.

SUBSYSTEMS DESCRIPTION

The following paragraphs contain a brief description of the 12 major avionics subsystems on the B-1. They are:

1. Automatic Flight Control Subsystem
2. Structural Mode Control Subsystem
3. Mission and Traffic Control Subsystem
4. Manual Flight Control Subsystem
5. Flight Instruments Subsystem
6. Navigation and Radar Subsystem
7. Avionics Multiplexing Subsystem
8. Central Integrated Test Subsystem
9. Electrical Multiplex Subsystem
10. Stores Management and Weapon Delivery Subsystem
11. Crash Data Recorder
12. Defensive Subsystem Group

Automatic Flight Control Subsystem (AFCS)

The AFCS includes that portion of the flight control system that provides the unpiloted automatic modes. They are automatic, in that the pilot does not

actively participate in the control law or logic, although he may in some cases introduce small biases or temporarily suspend the mode with control stick steering. The AFCS provides a variety of pitch and roll automatic guidance and pilot-assist modes of flight control operation, and provides automatic throttle control as well. The system basically consists of pilot's and copilot's control panels, an AFCS logic controller, and terrain-following radar adapters. The AFCS operates through the stability and control augmentation system (SCAS) providing pitch and roll commands to the SCAS controllers. The SCAS, when operated with the AFCS, provides improved aircraft stability in the pitch, roll, and yaw axes. The signals for AFCS are mainly discretes.

Structural Mode Control Subsystem (SMCS)

The SMCS is provided to assure the required ride quality performance specified. A cockpit switch provides engagement/disengagement capability. If a failure of the SMCS is detected, the vanes are centered and retained in the centered position. The input and output signals for the SMCS are discretes and dc analog.

Mission and Traffic Control (M&TC)

The M&TC equipment provides communication (intercom, UHF radio, HF radio), radio aids to navigation (TACAN, ILS), and aircraft identification (IFF). The radar altimeter, usually considered a part of the navigation and radar subsystem, has been included in the M&TC subsystem.

The HF radio is operated by the copilot, and all crewmembers can listen and talk. It provides air-to-air and air-to-ground long-range voice communications. Signals for the HF are discretes, analog, and audio of less than 5 vac.

The UHF provides air-to-air and air-to-ground line-of-sight range voice communication and can be operated by the pilot and copilot. Signals for the UHF are discretes and audio less than 5 vac.

The intercom provides interphone communication between all crewmembers and processing of radio control and audio signals. The signals are audio of less than 5 vac, discretes, and digital.

TACAN is operated by the pilot and copilot within line-of-sight range to 300 nautical miles. It provides bearing and distance information relative to a known ground beacon position.

The instrument landing system (ILS) provides visual indications to the pilot and copilot for manual and automatic approaches by using the localizer, glide slope, and marker beacon RF signals. The signals involved are audio, analog, and discretes.

The radar altimeter provides to the pilot altitude measurements from 0 to 5,000 feet above the terrain. The signals are discretes.

The rendezvous beacon identifies the B-1 to tanker aircraft to facilitate rendezvous. The signals are discretes.

The IFF identifies the B-1 to interrogating ATC radars for traffic control purposes. The signals are digital, discrete, and audio.

Manual Flight Control Subsystem (MFSC) and SCAS

The MFCS includes all of the primary and secondary flight controls (PFC and SFC). The PFC includes the SCAS. The MFCS consists of the cockpit controls, mechanical linkages, cables, electrical/electronic components, and hydraulic components which move the PFC and SFC surfaces. The SCAS interfaces with the AFCS to implement pilot-assist and guidance functions, with the SMCS to provide improved aircraft ride qualities, and with the central air data system (CADS) to provide speed stability and gain control. The signals are 0- to +5-volt dc and ac analog.

Flight Instruments

The flight instruments subsystem provides the pilot information on the relationship of the B-1 to the surrounding air mass and to the earth mass below. They consist of the gyro stabilization (GSS), central air data computer (CADC), rotation go-around/angle-of-attack/air vehicle limits (RGA/AOA/AVL) computer, flight director computer (FDC), and associate controls and indicators. The GSS provides heading, pitch, and roll attitude and rate-of turn reference data for the pilot's and copilot's horizontal situation indicator, vertical situation display, and standby attitude director indicator. The CADC performs the function of processing raw air data, computing data parameters, and communicating with the avionics control units (ACU). The signals for the various flight instruments and computers include analog, digital, and discrete signals.

Navigation and Radar

This subsystem provides global navigation capabilities by processing data obtained from various avionics systems sensors. The signals are discretes and ac synchro data.

The inertial navigation system (INS) consists of two LN-15 inertial measuring units (IMU) which output signals that reference the aircraft to the local vertical. Each IMU is tied to a dedicated inertial electronic

unit (IEU) which interfaces the IMU with the avionics computers. Computation of the amount of torque required to maintain the IMU gyros at local vertical is provided by the guidance navigation control avionics unit (GNACU), one of the two avionics computers. Roll and pitch data are provided by the IMU to the forward-looking radar (FLR), terrain-following radar (TFR), Doppler radar, and forward-looking infrared (FLIR).

The Doppler radar, AN/APN-200(Mod), utilizes the Doppler or frequency shift principle of a moving platform to extract aircraft drift and groundspeed information from radar returns.

The TFR, AN/APQ-146, provides terrain-following commands to manually or automatically fly the aircraft at any one of six preselected low-altitude terrain-clearance altitudes. The radar also operates in terrain-avoidance and ground map modes.

The FLR, AN/APQ-144, is a multimode, noncoherent, Ku-band radar which furnishes navigation fixtaking, bombing, and rendezvous information within a line-of-sight range of 200 miles.

The electro-optical viewing system (EVS) consists primarily of the FLIR, which scans the volume forward of the aircraft and processes the infrared energy received for presentation of a real-time video picture. The FLIR video can be viewed by the pilot and can be utilized for navigation or TF/TA backup.

Avionics Multiplexing Subsystem (AMUX)

The function of the AMUX is to provide a common data transmission system whereby the various offensive sensing, control, and display subsystems are interconnected to the avionics control units (ACU's) to provide the navigation and weapon release functions. Under ACU control, a particular subsystem may be interrogated, requested to transfer data to the ACU, or if commanded, receive data from the ACU. The data transferred are encoded into 24-bit words using Manchester II (biphase-L) in accordance with MIL-STD-442.

Central Integrated Test Subsystem (CITS)

CITS is an aircraft subsystem which continually and automatically tests the operability of all aircraft subsystems. The CITS configuration is based on the use of an onboard real-time computer to control data acquisitioning, data processing, and data dissemination operations for performing the B-1 subsystems test. The CITS comprises a digital computer with a software program which processes data to determine the operational status of subsystems, five data acquisition units (DAU's) for interfacing aircraft subsystems to provide

the computer with test data, a CITS control and display (CCD) panel for the man/machine interface, an airborne printer (AP) to provide immediate post-flight maintenance data, and a magnetic tape digital recorder to provide overall maintenance and logistics data. The analog signals are ±5 volts (dc to 600 Hz). Discrete signals are ±5 vdc. Serial digital signals are Manchester-type ±5 volts, 1 megabit/sec, 9 or 17 bits/word.

Electrical Multiplex System (EMUX)

The EMUX system performs the functions of receiving, formatting, and transmitting data on redundant data links, as well as providing logic processing for electrical power control, load management, and monitoring. The system also performs self-test and provides EMUX status and data to CITS. The digital signal format is two-way Manchester 24-bit words at 1 megabit/second rate. The discrete signals are +5 vdc. Figure 4 shows the left-hand data link for EMUX.

Stores Management and Weapons Delivery System

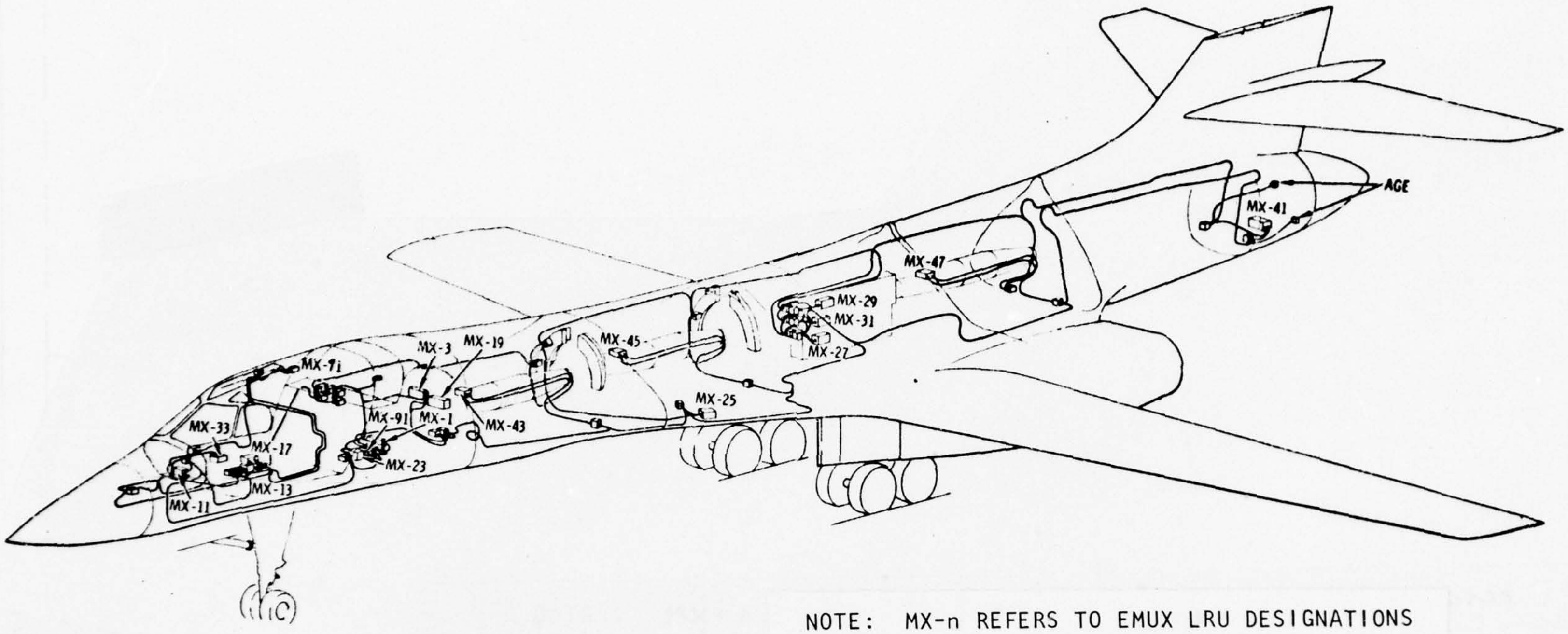
This system provides for the carriage installation, selection, arming, and safe deployment of offensive weapons. The basic system consists of the suspension and release equipment and the stores management system (SMS). Weapon release (nuclear and SRAM) is controlled by SMS selections and navigation and weapons delivery systems ACU's. All signals for the SMS are discretes and Manchester bipolar code.

Crash Data Recorder/Crash Position Indicator (CDR/CPI)

This system contains a deployable tape recorder/radio beacon package. Various aircraft operational parameter data and crew audio are recorded for use in crash investigations. The recorder/beacon package can be deployed by the crew or, automatically, by crash-sensing devices. Upon deployment, the radio beacon is activated on 243 MHz emergency frequency to assist in locating the data package and downed aircraft. The beacon has a minimum line-of-sight range of 50 n mi. Signals for the CDR/CPI are Manchester bipolar code and audio signals less than 5-volt RMS.

Defensive Subsystem Group (DSG)

The DSG is an advanced automated RF surveillance and electronic countermeasures system (RFS/ECMS) designed to enhance the B-1 penetration in the presence of hostile radar environments. The purpose of the DSG digital bus



NOTE: MX-n REFERS TO EMUX LRU DESIGNATIONS

Figure 4. B-1 EMUX data link (left side).

system is the high-speed transmission of data required to assess the electro-magnetic environment and control the operation of the ECM responses. The data transmission between the RFS/ECMS LRU's consists of parallel differential binary digital data with bit rates of 0.5, 1.25, and, at worst case, 5.0 mb/sec. The data also consist of pulse-width modulated analog data, with pulse width varying from 2 to 20 sec. The locations of the B-1 equipment and lines representing interlocation buses are shown in Figure 5.

SUBSYSTEMS DEFINITION

The FOCAP study was the beneficiary of two other fiber optics studies performed by Rockwell in the area of subsystems definition. From previous studies of potential fiber optics implementation in the DSG (Reference 2), the digital data buses contained in the DSG had been identified as candidates for fiber optics. A description of these buses was available (Reference 3) and was used in this study.

Concurrent with the FOCAP study, an initial screening process to identify data transfer subsystems (or portions thereof) of all B-1 electronics subsystems other than the DSG that might employ fiber optics links for data transmission was performed by Rockwell (IR&D funds) for one of the in-house fiber optics studies. This initial screening process was accomplished by (1) examining and analyzing the integrated wiring schematics of all major avionics subsystems, and (2) applying a set of guidelines to extract only those portions of the wiring that are suitable for fiber optics implementation. Only those wires that carry digital (or discrete), analog, or video information can be substituted with fibers. Power and RF signals cannot be transmitted via fibers. Accordingly, wiring servicing LRU's such as power supplies, relays, transformers, switches, waveguides, antenna assemblies, intercom outlets, micro switches, telephone jacks, etc, were eliminated from the integrated wiring schematics. This screening process was applied to all subsystems of the study, and wiring schematics for fiber optics implementation were constructed for each subsystem. A total of 22 such wiring schematics were derived, and are documented in Reference 4.

The wiring schematics produced during the IR&D study were used in conjunction with other data such as wire lists, master equipment lists, and area routing diagrams to produce wiring block diagrams showing LRU's and their location by aircraft area; data line interconnects; wiring type, quantity, and length; shielding; conduits, and bulkhead connectors. These drawings form the basis for installation and weight studies of the existing data bus wiring. These drawings were also used as an aid in the fiber optics conceptual design. The stylized block diagram of the B-1 and the symbology used in the drawing were developed for the FOCAP program.

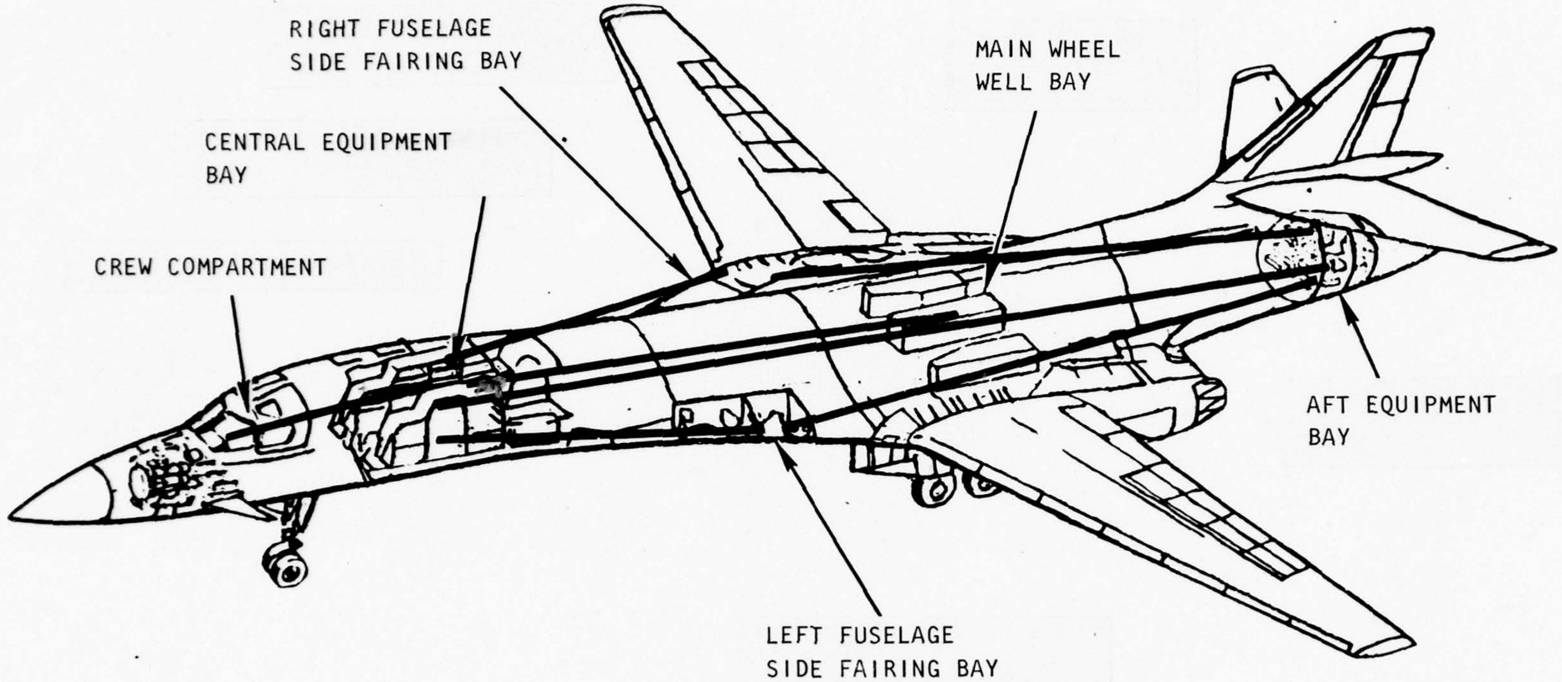


Figure 5. DSG equipment locations.

The list shown on each drawing of wiring components removable in a fiber optics implementation was developed in accordance with the definition of the retrofit and new design subsystems. The total number of subsystems implemented in fiber optics is a study variable. Thus, it was necessary to develop a method of allocating components to a subsystem, since the component may be shared by several subsystems. Typically, this was accomplished by allocating to a subsystem that part of the full component used by the subsystem. For example, if a subsystem used 25 pins out of the estimated average 100 pins used in the typical bulkhead connector, then 0.25 bulkhead connector was allocated to this subsystem for this bulkhead penetration.

Detailed installation assumptions for particular subsystem components are as follows:

1. Electrical Conduit and Overbraid Cable. Conduit and overbraid were removed on new design concepts only and not in retrofit studies. The quantity of conduits and overbraid considered for removal is based on the following assumptions:

    a. Conduit and overbraid is not installed on wiring inside a hardened bay except for the stores management system.

    b. Outside the hardened bays, 10 percent of the wiring is in physical protective conduit and 90 percent of the wiring is contained in EMI/EMP protection conduits or overbraid. This EMI/EMP protected wire is 50 percent in conduit and 50 percent in overbraid.

    c. For an interconnecting wire between hardened and nonhardened bays, 20 percent of the wire is in the hardened bay and 80 percent of the wire is in the nonhardened bay.

    d. The typical conduit is 1.25-inch-diameter by 0.020-inch-thick molypermalloy; for the average 60-percent fill, there are 50 two-conductor shielded 24-gage cables.

    e. The typical overbraid is 0.75-inch diameter, two layers; for a complete fill, there are 30 two-conductor shielded 24-gage cables.

2. Electrical Bulkhead Connectors. Figures for the electrical bulkhead connectors that are candidates for removal are based on 128 pin connectors, with 100 active and 28 spare pins. The number of candidate bulkhead connectors removable in a fiber optics implementation of a subsystem is 1/100 of the bulkhead wire penetrations in that subsystem. (Only bulkheads that already have connectors are considered as penetration points.) Bulkhead connectors were removed with new design concepts but not for retrofit studies.

3. <u>Wire Shielding and Shield Grounds</u>. Candidate wiring in all systems except NAVS & RADAR and DSG are in two-conductor shielded cables. NAVS & RADAR wire is 80 percent in two-conductor shielded cables and 20 percent in three-conductor shielded cables. DSG wire is in various sizes of multiple-conductor shielded cables, as defined in reference 2. One 6-inch-long shield ground wire is estimated for each end of each shielded cable.

The installation block wiring diagrams developed during the study are shown in drawings 2-1 through 2-10 of Reference 1. Table 3 contains a list of wiring statistics.

TABLE 3. B-1 AIRCRAFT WIRING STATISTICS

Wire footage	
Shielded wire	508,280 ft
Shield grounds	21,963 ft
Unshielded wire	216,716 ft
Total wire	746,959 ft
Wire segment	
Shielded signal paths	50,828
Unshielded signal paths	21,732
Signal paths	72,560
Shield grounds	43,926
Total segments	116,486
Bulkhead connector	93
Conduit footage	3,431 ft
Overbraid cable footage	6,628 ft
Major equipment items	983

A summary of the installation items for each subsystem is contained in Table 4. For reference, the totals of the subsystem are compared with the aircraft totals from Table 3. Of the 983 major LRU's on the aircraft, 351 (or about 36 percent) are included in this study. About 17 percent of the wire segments and 19 percent of the total wire footage are also included.

FIBER OPTICS IMPLEMENTATION

Conceptual fiber optics designs were made for all subsystems identified in the baseline description. This section contains (1) a list of fiber components used in the study, (2) a description of the methodology used in the conceptual fiber optics design process, and (3) a description of the resulting fiber optics conceptual designs, including a discussion of multiplexing conceptual designs, where appropriate.

COMPONENT SURVEY AND SELECTION

Component Data Bank

A state-of-the-art survey of fiber optics data transmission system components was conducted during a previous IR&D study (Reference 2) on the B-1 DSG. It was updated during phase I of FOCAP to provide a data bank to be used as the basis for selecting components for new and retrofit fiber optic data links under study. The data bank is included as Appendix A primarily for information purposes, although many of the components listed in the tables are unsuitable for use on the B-1 for various reasons. The performance, physical characteristics, and availability of fiber optic cables, connectors, couplers, LED's, and photo-detectors are summarized in this appendix. The characteristics of supporting electronics are peculiar to the subsystem and are discussed in the subsystem description.

The data were collected by contacting Government agencies (Naval Ocean Systems Center (NOSC, formerly NELC), San Diego, California; Air Force Avionics Laboratory (AFAL); WPAFB, Dayton, Ohio), approximately 35 suppliers of fiber optics systems components and systems, and through a thorough and comprehensive literature search. A list of agencies and suppliers contacted is also included in appendix A.

Physical and Environmental Effects

The physical and environmental effects on the components of a fiber optics subsystem are discussed in the following paragraphs. A summary of the B-1 aircraft environment is shown in Table 5.

TABLE 4. WIRING INSTALLATION ITEMS SUMMARY

System No.	System Title	LRU's Affected ②	Candidate Wiring (for Replacement)							
			Number of Wire Segments			Avg Wire Gage	Total Wire Footage	Bulkhead Connector Allocation ①	1-1/4 Dia Rigid Conduit Allocation (in feet)	3/4 Dia Overbraid Cable Allocation (in feet)
			Signal Paths	Shield Grounds	Total					
1	EMUX	26	370	370	740	24	2,700	0.3	8.6	14.4
2	AMUX	27	270	270	540	24	2,300	0.2	6.6	11.0
3	CITS	10	70	70	140	24	600	0.1	1.9	3.2
4	Flight Instr	28	1,150	1150	2,300	24	7,850	2.7	16.5	27.6
5	Flight Cont	90	1,000	1000	2,000	24	13,100	1.8	48.7	81.2
6	NAVS & Radar	27	1,175	1100	2,275	22	12,000	3.0	36.3	60.6
7	Stores Mgmt	36	880	880	1,760	24	9,100	2.4	35.1	68.0
8	M&TC	52	1,200	1200	2,400	22	11,500	2.1	37.7	62.8
9	Crash Recorder	13	150	150	300	22	4,000	0.2	14.8	24.8
10	DSG	42	6,900	340	7,225	24	79,600	22.0	220.0	365.0
Totals		351	13,165	6530	19,680		142,750	34.8	426.2	718.6
DSG		35.7%	18.1%	14.9%	16.9%		19.1%	37.4%	12.4%	10.8%

NOTES: ① Based on 100 active pins in an MS27656T25F35P recept/ES274-67T25F35S plug with 128 pins.

② Exclusive of switches, jacks, lights, terminal boards, relays, circuit breakers, sensors, valves, solenoids, heaters, pumps, antennas, detectors, batteries, transformers, dimmers, power supplies, termination boxes, etc.

TABLE 5. B-1 AIRCRAFT ENVIRONMENT

Transient nuclear effects (level classified)

EMP, gamma dose, gamma dose rate, neutrons

EMI

14 KHz to 35 MHz	10 volts/meter
>35 MHz to 10 GHz	5 volts/meter
>10 GHz to 18 GHz	20 volts/meter

Acoustic noise, 142 db

Vibration

Sinusoidal, 12 G peak

Random, 0.7 G^2/Hz

Temperature

	Electronics	Cabling
Operating	-65° to 160°F (-53.8° to 71.1°C)	-65° to 265°F (-53.8° to 129°C)
Nonoperating	-65° to 203°F (-53.8° to 95°C)	-65° to 265°F (-53.8° to 129°C)

Fiber Optic Cable

The temperature range of the fiber optic cable is primarily a function of the type of jacket material used. This is true for glass clad, glass core fiber, and plastic clad, fused silica core fiber, since the melting points of these fibers are much higher than that of the typical jacket materials being used. Supplier data show the temperature ranges for the common jacket materials to be:

1. Hytrel, -55° to 150° C

2. PVC, -10° to 105° C

3. Tefzel, -55° to 150° C

The exception to the preceding is the plastic clad, plastic core (polystyrene, polymethyl methacrylate) fibers. These fibers have a useful temperature range between -40° and 82° C. The temperature range requirement for the B-1 is between -54° and 130° C. Thus, the plastic core, plastic clad fibers cannot be used on the B-1.

The mechanical properties of fiber optic cable include tensile strength, bend radius, crush resistance, and resistance to vibration damage. Tensile strength of fiber optic cable is primarily a function of the strength of the jacket material and added strength members. The three common jacket materials (i.e., PVC, Hytrel, and Tefzel) can provide up to 10 pounds of tensile strength without the addition of strength members. The most common strength member is an aramid yarn-like material from DuPont, called Kevlar. A 0.024-inch-diameter bundle of Kevlar can provide a 120-pound tensile strength, and a 0.030-inch-diameter bundle can provide 180-pound tensile strength. Fiber optic cable suppliers are using Kevlar in 50-pound-strength bundles. For example, Valtec uses four Kevlar strength members in the 19-fiber plastic clad, fused silica, Hytrel-jacketed cable, which has a 200-pound tensile strength. Galileo also uses axial Kevlar strength members, but in addition adds a layer of braided Kevlar, which gives the Tefzel jacketed fiber optic cables approximately 400-pound tensile strength. The jackets and strength members are secured to the fiber optic cable fittings. Therefore, the load is on the jacket and fittings, and not on the optical fibers.

Bend radius of fiber optic cables is primarily a function of the type of jacketing material being used. DuPont has tested the S120R plastic clad, fused silica single-fiber cable and determined the minimum bend radius to be 0.125 inch. The cable was able to sustain a weight of 176 pounds while around a 0.25-inch mandrel. Corning recommends a minimum bend radius of 1.0 inch for the seven-fiber Corguide, and 3.9 inches for the 19-fiber B-19 cable. Galileo specified the minimum bend radius for Galite 4000 plastic clad, fused silica as 0.20 inch for a PVC jacket, 0.275 inch for a Tefzel jacket, and 0.75 inch for a Kevlar-strengthened Tefzel jacket, containing one, seven, or 19 fibers.

No known test specifications are available for crush resistance. However, some testing has been performed at Galileo on a 19-fiber, plastic clad, fused silica core, Tefzel-jacketed cable with axial and braided Kevlar strength members. A 10-pound weight was dropped on the cable 100 times from a height of 6 inches. At the conclusion of the test, only one optical fiber was broken. Other cable suppliers claim good crush resistance, but no quantitative data are available.

Data on vibration testing of fiber optic cable are relatively sparse. No data are available from fiber optic cable suppliers, who generally do not have the facilities to perform vibration testing. However, numerous tests have been performed by NOSC in conjunction with the A-7 airborne light optical fiber technology (ALOFT) program. The vibration levels tested are those specified in MIL-E-5400P. The method outlined in MIL-T-5422F was used. No resonances were found, and no fiber breakage or optical degradation occurred for any of various frequencies and temperatures.

The B-1 is a strategic aircraft designed to perform its mission and survive in a nuclear environment. The effect of nuclear radiation on the optical properties of various optical fibers has been studied extensively by Sandia. Tests show that plastic clad, fused silica fibers, some germanium-doped-fused silica fibers, and plastic clad, plastic core fibers have excellent resistance to nuclear radiation. Studies have indicated these fibers are acceptable on the B-1 from this viewpoint (refer to appendix B). Glass core, glass clad fibers suffer severe optical degradation due to ionization of impurities in glass.

Connectors

Information on the operating temperature ranges for fiber optic cable connectors was obtained from Amphenol and ITT/Cannon. Fiber optic cable connectors made by Amphenol have an operating temperature range between -55° and 199° C. The Amphenol connectors meet temperature cycling requirements of MIL-STD-202, method 102, test condition C. ITT/Cannon fiber optic connectors are made according to requirements of MIL-C-39012, MIL-C-83733, and MIL-C-83723.

Amphenol fiber optic cable connectors are expected to meet the shock requirements of MIL-STD-202, method 202 (acceleration = 50 G at 7 milliseconds); vibration requirements of MIL-STD-202, method 204 (test condition D); and corrosion requirements of MIL-STD-202, method 101 (test condition B, 5-percent salt solution). ITT/Cannon states that their connectors "will meet the applicable requirements of current military specifications."

No specific data on connector susceptibility to nuclear radiation are available, but there is no reason to believe that connectors are susceptible to nuclear effects.

LED's and Photodetectors

The operating temperature range for LED's and photodiodes varies from supplier to supplier and device to device. Fairchild specifies the operating temperature range between -55° to 100° C for the FPE-104 LED, and -10° to 100° C for the FPE 100 LED. RCA specifies operating temperature between -40° to 125° C for SG 1009 LED, -73° to 75° C and for SG 1001 LED. Spectronics specifies the operating temperature for the SPX 1775, SPX 2231, and SPC 2354 LED's between -65° and 125° C. RCA specifies the operating temperature for all of its photodetectors to be between -40° and 80° C. Spectronics specifies the operating temperature for the SPX 1777, SPX 2232, and SD 5426 photodetectors to be between -65° and 125° C.

The relative output of LED's as a function of temperature was specified by Bell-Northern Research for their single-fiber LED's and by Fairchild for the FPE 100. Bell-Northern specifies that the relative output power of the BNR 40-3-10-2, 40-3-15-2, and 40-3-30-2 LED's is 1.1 at -25° C, 1.0 at 25° C, and 0.9 at 75° C. The operating temperature range for these devices is -40° to 85° C. Fairchild specifies that the relative radiant output be 100 percent at 25° C, 80 percent at 50° C, 65 percent at 75° C, and 55 percent at 100° C. Spectronics reports that their LED's output power degrades 0.044 db per degree C temperature increase.

LED's are susceptible to gamma radiation and suffer degradation at high total gamma dose levels. At a level equivalent to 10^7 rads in silicon material (10^7 rads Si), the quantum efficiency of typical LED's is reduced to 50 percent. Above this value, the quantum efficiency decreases almost exponentially, and at 10^8 rads Si, it is degraded by a factor of 300. At the B-1 total gamma dose requirement level, no degrading effects are expected to occur on the LED's.

Neutrons inflict permanent damage which is exhibited by a reduction in the LED quantum efficiency at fluence levels above 10^{13} neutrons per square centimeter. At the B-1 requirement fluence level, a reduction in the external quantum efficiency of approximately 15 percent is expected.

A transient pulse of ionization (prompt gamma) incident on an LED will produce electron hole pairs in the region of the P-N junction, resulting in a forward current flow due to forward biasing. If the intensity is great enough, photon output will be generated for the duration of the pulse, with the LED resuming normal operation afterwards. The intensity required to generate light is 3.5×10^{10} rads Si per second for a typical LED. At B-1 prompt gamma levels, no effect is expected.

Total gamma dose susceptibility of photodiodes ranges from 104 to 106 rads Si. The effects are in the form of permanent degradation of the diodes current-voltage characteristic curve. No effects are expected at the B-1 total gamma dose requirement level.

A photodiode becomes vulnerable to neutron effects at a fluence level of approximately 10^{17} neutrons per square centimeter, where junction capacitance and series resistance are degraded. The quantum efficiency will generally be independent of neutron radiation since the device is operated in the fully depleted region (reverse bias), where absorption of all incident quanta takes place only in the intrinsic layer. At B-1 requirement neutron fluence levels, no detectable effects will occur.

Photodiodes generally respond to prompt gamma radiation by producing a forward current waveform which follows the waveform of the gamma pulse quite closely. This response is facilitated by the reverse bias operation of the photodiode. Similar devices are used to monitor gamma intensity in flash X-ray radiation testing with good reliability. Tests performed by Singer-Kearfott indicate induced photocurrents of 10 to 100 ma at gamma dose rates of 10^6 to 10^8 rads Si per second. These current transients are easily handled by the diode structure, which is designed to prevent high surge currents and diode burnout. At B-1 levels, transient upset due to prompt gamma is expected, with recovery to normal following the gamma pulse. Various integrated circuit components presently used in B-1 avionics have response waveforms at their output terminals which are device dependent and do recover to pregamma state in zero to 50 µseconds. The loss of one data bit or data frame is the only expected result of exposure to prompt gamma. A more detailed analysis of expected fiber optics nuclear effects is contained in appendix B.

Flight Test Data

Environmental effects on a total fiber optic data transmission system were evaluated during the Navy/IBM A-7 ALOFT demonstration study under laboratory conditions by LTV, Dallas, Texas, and by NOSC, San Diego, California, during flight test. The LTV testing included a 3-month ground test of the IBM hardware while installed in an avionics simulator of the A-7 navigation and weapon delivery system (N/WDS). The purpose of the testing was to insure compatibility of the hardware and software of the A-7 N/WDS and gather environmental test data on the fiber optics links before going into flight test. A data link identical to that installed on the A-7 was subjected to the following tests under operating and nonoperating conditions:

- Temperature/altitude as defined in MIL-E-5400P, class 2, operation

- Temperature extremes as defined in LTV report 2-50360/4R-5738, "Environmental Definition Analysis Report," dated 23 September 1974

- Temperature and shock as defined in MIL-E-5400P, class 2, nonoperation

The test results indicated that the fiber optic components will survive aboard the A-7 aircraft. The tests also demonstrated that the fiber optic components will not degrade the N/WDS performance when exposed to the A-7 environment.

During the subsequent flight test of the A-7 ALOFT aircraft at NWC, China Lake, during June 1976, the fiber optic system demonstrated performance equal to that of the hardware system it replaced. The pilots of the flight test aircraft reported "no difference" between the two systems.

Summary

Based on the preceding discussions and the IR&D study for DSG, it is concluded that fiber optics components are either available or can be developed to perform satisfactorily in the B-1 environment.

Fiber cables, both in bundles and as singles, are available from numerous suppliers. The attenuation of the fibers varies from 20 to 1,200 db/Km.

A multitude of connectors and couplers are available for fiber bundles. Connectors and couplers for single fibers are under developement.

LED's and photodetectors are available in a great variety. The risetimes of LED's vary from 1 to 20 ns; photodetectors with risetimes less than 10 ns are common.

A fair amount of environmental testing has been performed on the components and on total fiber optics data transfer systems, although no military specification or standards have been written on any of the components. The data available, however, give high confidence that fiber optics data transfer components can work satisfactorily in the B-1 thermal, vibration, and nuclear environment.

Components Selection and Description

A baseline set of components was selected for conceptual fiber optic design for the FOCAP study. These components are as follows.

Light-Emitting Diodes (LED's)

Device: Spectronics SPX1775

Output: 2 mw minimum at 100 ma at 907 nanometers (nm), up to 5 mw at higher current (50-percent duty cycle)

Rise time: 20 nsec

Selection criteria: More data are available on this LED than most others. The LED was designed for military data bus applications and has demonstrated system performance. Output power is higher than most.

Photodiodes

Device: Spectronics SPX1777

Response: 0.64 amp/watt

Rise time: 1.5 nsec

Selection criteria: Same as for LED. Response is better than most.

Fiber Cable

Type: Plastic clad, fused silica (e.g., Valtec PC-05)

Calculated numerical aperture: 0.30

Fiber diameter: 0.006 in.

Fiber core diameter: 0.005 in.

Number of fibers: 19

Bundle diameter, exclusive of sheathing: 0.030 in.

Packing fraction: 0.528

Attenuation: The specification for this cable is 40 db/Km at 820 nm. At 907 nm, the attenuation is estimated to be 100 db/Km, including noncontinuous fiber effects.

Jacket Material: Tefzel or nonflammable Hytrel

Strength members: Kevlar

Cable diameter: 0.11 in.

Cable weight: 7 lb/1,000 ft

Selection Criteria: This type of fiber is more resistant to nuclear effects than others and meets the temperature requirements. Kevlar strength members are necessary to meet the pull strength requirement of 33 pounds. This fiber has a high numerical aperture and packing fraction relative to other nuclear resistant fibers.

Couplers

The function of a coupler is to distribute an optical signal among multiple optical paths, forming the optical analog to the electrical splice point. Two types of couplers were employed in the FOCAP study: radial-arm or star couplers, and Y-couplers.

Star Coupler

Device: Spectronics radial arm

Internal loss: 1.5 db

Connector loss: 5 db

Selection criteria: The aforementioned projected loss performance is the best known. This type coupler has been designed and used in a system employing most of the other components listed here.

Y-Coupler

The device employed in the FOCAP study is a conceptual design only; no device having exactly the characteristics conceived is known to exist, but there are no known technological hurdles to its manufacture. Conceptually, the device consists of a tapered mixing rod made of pure fused silica, coated on each end with an antireflectance coating, and on the curved surface by the same plastic coatings used in fiber manufacture. The diameter of the rod is 0.030 inch on one end, corresponding to the bundle diameter of the fiber

cable used, and about 0.042 inch on the other, corresponding to the diameter of a composite bundle made up of the junction of two 19-fiber bundles. The length of the rod is estimated to be on the order of 0.5 inch.

For a properly designed coupler, the loss encountered in going from the single bundle to two bundles would be the sum of the power split and a connector loss, or about 7 db. The loss encountered in going in the reverse direction should be less. A 7 db loss is assumed in each direction for the FOCAP study.

Connectors

No specific connector was identified as a baseline in the FOCAP study. A great many connectors exist, and they are typically modified MIL-qualified wiring connectors. The optical performance of the system at a connector is almost entirely a function of the fiber cable used and its termination technique; the primary function of the connector is to hold the fiber bundles in alinement. The FOCAP study assumes that the LED's and photodiodes in the E-O conversion electronics will be mountable in the connector on an LRU; this is the only significant constraint unique to fiber optics imposed upon connector selection. For the purposes of making fiber optics block diagram layouts and weight estimates, the Deutsch series of fiber optics connectors was used.

POWER BUDGETING

Power budgeting is the process of comparing projected link losses with those losses allowed, to assure that the communication link will operate satisfactorily (i.e., that it has a satisfactory projected S/N ratio or bit error rate (BER)). The link analysis used in the FOCAP study depends heavily upon work performed by Spectronics, Inc, for the Air Force.

Allowable Link Loss

The allowable link loss is that sum of the losses allocable to a system with which the system will properly operate. The factors affecting the allowable link loss are the LED output, the receiver sensitivity, and the required signal-to-noise ratio.

LED Output

The signal source selected for FOCAP is the Spectronics SPX1775 LED, or equivalent. This LED has a 2 mw minimum output at 907 nm with a driving current of 100 ma. At higher driving current, outputs of 5 mw are achievable.

In this study, outputs ranging from 1 mw (0 dbm) to 5 mw (7 dbm) were assumed. The larger values were used when necessary to achieve a desired link margin of 6 db minimum. The effect of the thermal and nuclear environments were not included in the LED output assumption. It is anticipated that within the time frame of the FOCAP study, LED's less susceptible than those currently available could be developed. For the worst case, present LED's would degrade between 1 and 5 db due to temperature, and less than 1 db due to nuclear effects.

Receiver Sensitivity

Two receiver concepts were employed in the FOCAP study. These are the "variable receiver" and the "fixed receiver."

Variable Receiver. The sensitivity of the variable receiver using a Spectronics SPX1777 or equivalent PIN photodiode is being projected using the Spectronics recommended detection scheme (reference 5). This concept assumes that the receiver is a system design variable, and that the receiver will be optimized for the system data rate. For digital data bus systems, the sensitivity (i.e., signal power for S/N = 1) as a function of data bus rate is as follows:

Data bus rate (mb/s)	Sensitivity (nw)	Sensitivity (dbm)
1	0.46	-63.4
2	0.92	-60.3
5	2.3	-56.3
7	3.3	-54.8
10	4.7	-53.2
20	9.8	-50.1
30	15	-48.2
40	21	-46.8

The effective bandwidth (and, hence, the sensitivity) of the receiver is also a function of the effective risetimes of the other components of the

communication link. An approximate expression of the overall risetime of successive nonidentical stages is (Reference 6):

$$t = 1.1 \sqrt{t_1^2 + t_2^2 + \ldots + t_n^2}$$

where t is the overall risetime and t_i is the risetime associated with the ith stage. This relationship can be used to compute the effective receiver sensitivity degradation as a function of the other link component risetimes. The degradation in receiver sensitivity as a function of the bus data rate and LED risetime is shown in Figure 6. The 1.5 ns photodiode risetime is that for the Spectronics SPX1777. The 5 ns fiber risetime is appropriate for a 150-foot length of fused silica fiber having a numerical aperture of 0.30 using the relationship

$$\text{risetime} = \frac{(\text{numerical aperture})^2 \times \text{length}}{2 \times \text{index of refraction} \times \text{speed of light}}$$

The degradation shown in Figure 6 is conservative for low data rates.

Fixed Receiver. The foregoing discussion assumes that the receiver is a system design variable. The FOCAP study also includes designs where the receiver being developed by the Air Force is used. This receiver is a fixed design, designed for operation at 10 mb/sec; it will toggle at 300 n watts (-35.2 dbm) and achieve a bit error rate (BER) of 10^{-8}. For the FOCAP study, it was assumed that the receiver would operate at a sensitivity of -34 dbm and achieve a BER of 10^{-10}.

Required Signal-to-Noise Ratio (S/N)

For digital data buses using the variable receiver, the BER is related to the S/N as follows (References 4, 5, and 7):

BER	S/N	S/N (db)
10^{-8}	17.4	12.4
10^{-9}	18.6	12.7
10^{-10}	19.8	13.0
10^{-11}	20.8	13.2
10^{-12}	21.9	13.4

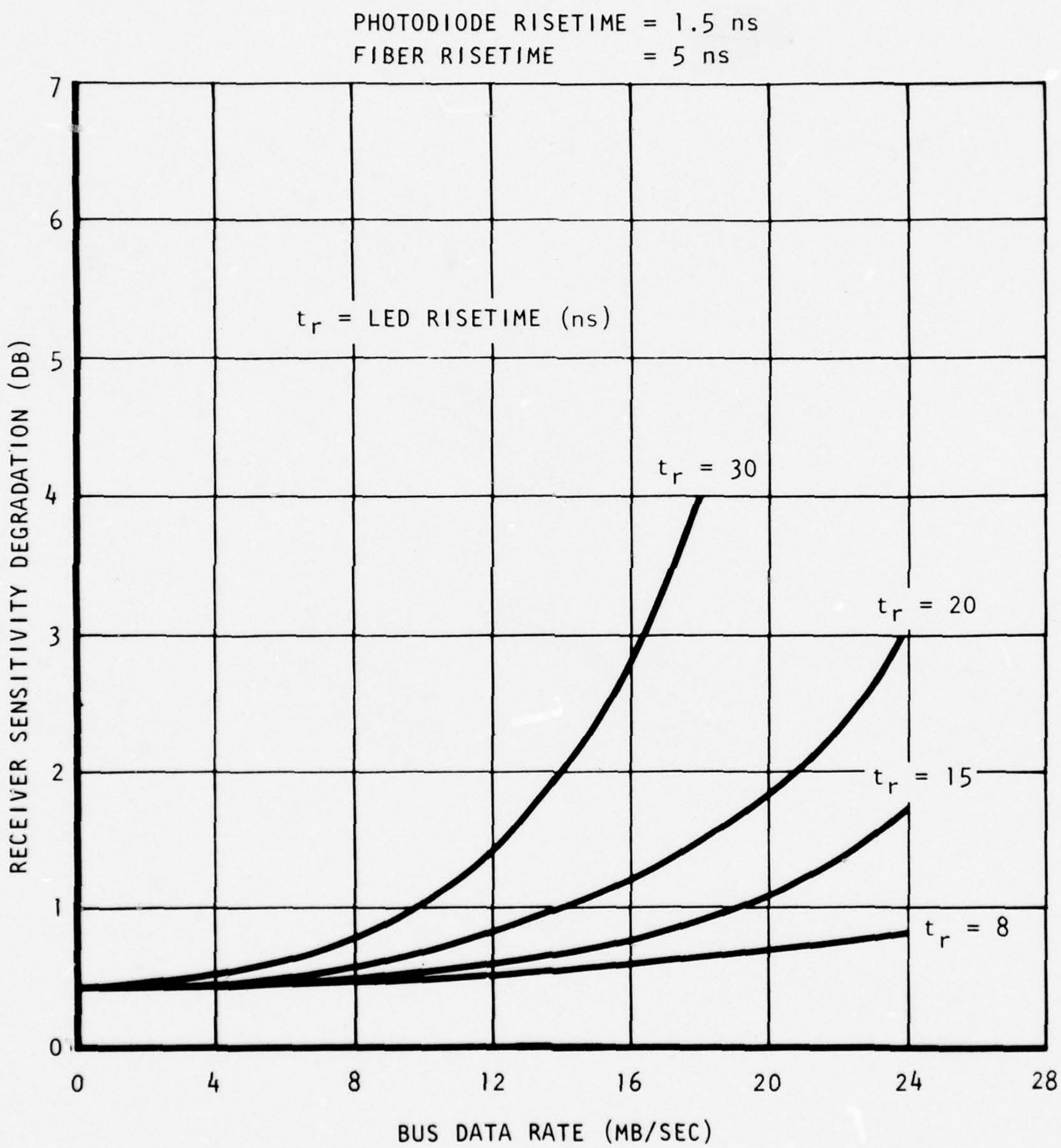


Figure 6. Effect of LED risetime on receiver sensitivity.

Typically, the B-1 data bus systems require a BER of 10^{-8}. Because of the relative insensitivity of the S/N to the BER, and to compensate for cumulative BER caused by repeated signals, a S/N of 13 db is being used for all configurations in this study.

Link Losses

The link loss is dependent upon the components used. Typically, these components consist of the fiber cable, bulkhead connectors, star (or radial arm) couplers, and Y-couplers.

Fiber Attenuation

The Valtec plastic clad, pure fused silica cable, or equivalent, has been selected as the baseline for the B-1 FOCAP studies on the basis of its nuclear hardness, high numerical aperture, relatively low loss, and high packing fraction. The attenuation of this fiber is nominally 40 db/Km at 820 nm, but the attenuation of the fibers increases at 907 nm, the nominal output wavelength of the Spectronics SPX1775 LED. For the purposes of the link analyses performed for this study, an attenuation of 100 db/Km is being used. This value includes noncontinuous fiber effects.

Bulkhead Connectors

A bulkhead bundle-to-bundle connector loss of 4 db has been assumed in the FOCAP study. A theoretical analysis projects a 2.8 db loss due to packing fraction and 0.3 db loss due to surface reflection, for a total loss of 3.1 db. The same theoretical approach predicts 2.0 db loss for the A-7 ALOFT fiber cable (367 glass core/glass clad fibers). The industry has, however, consistently measured 3.0 db connector loss for the A-7 ALOFT fibers, or 1 db excess loss over the theoretical predictions. This excess loss is attributed to imperfections in termination techniques. The same excess loss should be achievable on the plastic clad,fused silica (PCFS) fiber, resulting in a 4 db connector loss.

Suppliers of fiber optic cable and connectors and companies doing applied fiber optic data transmission system research were contacted to reevaluate the industry's experience with this cable. Among those companies contacted were:

1. Amphenol Connector Division of Bunker-Ramo
2. ITT/Cannon
3. Valtec Co, Fiber Optics Division

4. Spectronics, Inc

5. Galileo Electro-Optics Corp

6. Boeing Co

Three of the preceding companies actually measured the connector losses and report values ranging from 6 to 8 db, as compared to the estimated 4 db. The consensus among the cable users is that the excess loss is attributable to the plastic cladding for one reason or another. Among the possible causes of the excess losses mentioned by the users are (1) poor concentricity and cladding thickness control, (2) cladding damage due to poor core/cladding adhesive, (3) use of an epoxy with a refractive index similar to that of the core, and (4) change in the refractive index of the plastic upon being squeezed during the cable termination process. Among the suggested remedies are better quality control during manufacture, the use of a new harder plastic on Teflon-type cladding, and/or the use of an epoxy having a refractive index similar to that of the cladding.

Based on the foregoing survey, a 4 db connector loss for the PCFS fiber appears to be achievable even though this is presently an optimistic figure. Therefore, a 4 db connector loss has been assumed in this study.

Coupler Losses

The loss at the LED/fiber bundle interface is assumed to be 10 db. A loss of 10.5 db has been achieved by Spectronics using an annular ring fiber bundle configuration, and they project that 7.3 db should be achievable. The loss at the photodiode/fiber bundle interface is small. For link analysis, it is assumed to be zero in concurrence with Spectronics' practice, in which the responsivity of the photodiode is measured using a fiber optic bundle; therefore, any interface loss is included in the photodiode performance characteristics.

The loss associated with a star coupler can be divided into two components: internal loss and loss at the coupler/bundle interface. According to Spectronics, current internal loss is 4 to 5 db, with 1 to 2 db projected as achievable; 1.5 db is being used in the FOCAP study. Current coupler/bundle interface losses are 6 to 10 db, and 4.2 db is expected. A figure of 5 db is being used. A Y-coupler using a mixing rod is being projected to have a loss of 7 db, including the power split.

SUBSYSTEMS DESIGN

The preceding criteria have been applied to the conceptual design of fiber optics subsystems. In this section, the resulting fiber optics concepts and their link margins are discussed. Also discussed are the E-O interface adapters unique to each subsystem, and multiplexing concepts where appropriate. The installation block diagram for each subsystem described in this section is contained in Reference 1.

EMUX, AMUX, and CITS

EMUX, AMUX, and CITS are 1 mb/sec multiplexed data bus subsystems, and will be discussed jointly.

E-O Interface Adaptation

EMUX, AMUX, and CITS are very similar in terms of conversion to fiber optics. The existing multiplex data rate is well within the state-of-the-art in terms of circuit development and encoding or decoding techniques. The major emphasis in terms of building the E-O adapters is to compact the circuitry through use of available techniques such as CMOS or low-power Schottky devices. These state-of-the-art devices will provide multiplex rates of 10's of mb/sec. Retrofit and new-design implementations will be discussed.

Retrofit. In the retrofit design, a small adapter unit is added internally to the LRU and is connected to the multiplex output of the LRU. This unit performs the electrical-to-optical and optical-to-electrical signal conversion shown in Figure 7. The LED photodiode and associated electronics are mounted behind the LRU connector. The technical descriptions of these adapters were developed for the FOCAP study and are discussed in detail in Appendix C. There are three different types of adapters; the type A is used for conversion of the CITS LRU's, type B is used by the AMUX, and type C is used by EMUX LRU's. These adapters were designed to be easily installed in the LRU's and to least affect the LRU. The types A and B adapters for CITS and AMUX require two LED's and photodiodes per channel; the positive and negative Manchester excursions are transmitted on separate channels. This requirement is imposed by the detection and synchronization schemes used in CITS and AMUX, and there is no feasible way of avoiding the requirement without modification of existing circuitry. The EMUX adaptation does not impose this requirement on the fiber optics design. The technical description of the fiber optics adapters presented in Appendix C is sufficiently general to apply to all fiber optics concepts under consideration.

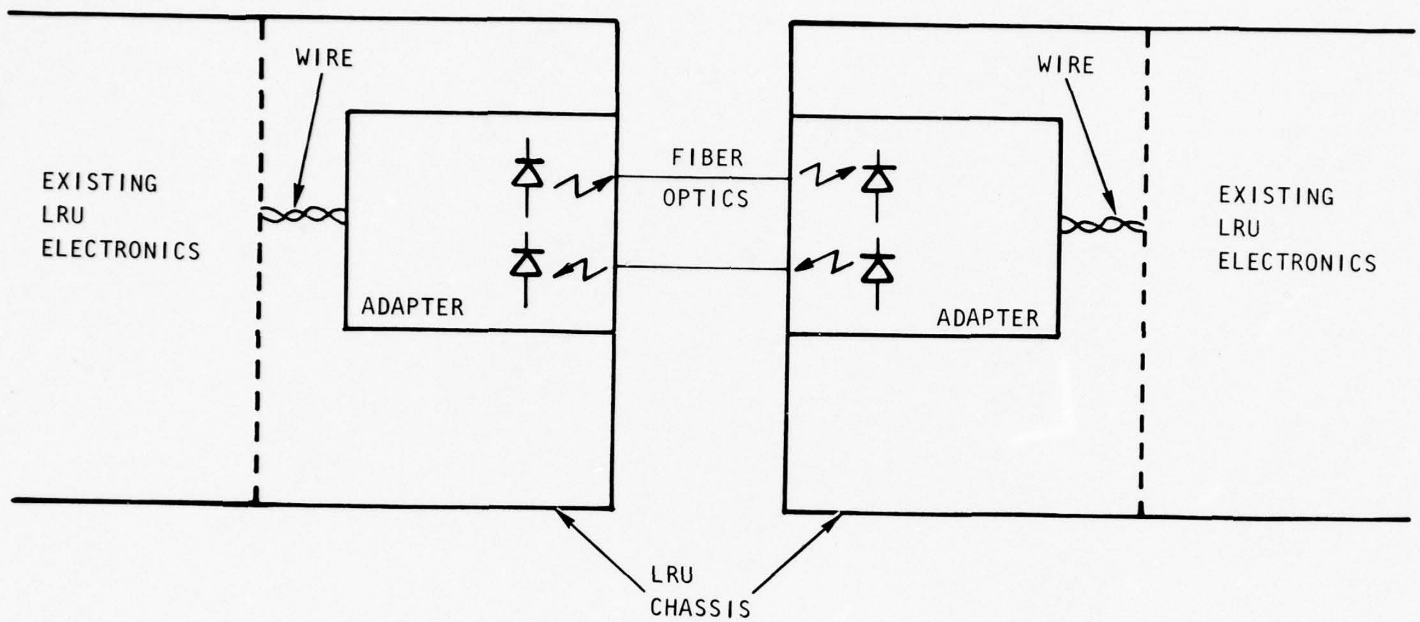


Figure 7. E-O retrofit implementation for EMUX, AMUX, and CITS.

New Design. The new design approach consists of redesigning the existing multiplexing sections of the LRU's. The existing electrical interface usually consists of a transformer, a receiver/transmitter section, an MUX and a de-MUX section, and parallel or serial shift registers and sync/parity generators. The replacement fiber optics electronics contains similar components but is tailored for optical transmission. The fiber interface modules (FIM) requirements formulated for the EMUX and CITS subsystems are presented in appendix D. Those LRU's interfacing on the AMUX presently utilize either a three-card I/O modem or a standard multiplex interface module (MIM). Therefore, a fiber optical module that is essentially the same as the MIM in terms of form, fit, and functions was designed. The fiber optic MIM (FOMIM) requirements are discussed in appendix E. For the new design fiber optics concept, only one LED/photodiode set is required per data channel.

E-O Adaptation Installation Impact. Design-to-parameters (weight, volume, etc) developed for the interface adaptations were forwarded to respective suppliers. Their estimated impact of installing the E-O adapters in various LRU's comprising the EMUX, AMUX, and CITS subsystems is shown in Table 6. These data were furnished by the LRU supplier. Cost data submitted concurrently are included for informational purposes.

As can be seen by inspection of the data, the physical impact of fiber optics on the LRU's is generally small and reasonably consistent. The costs show a wide variation from supplier to supplier. The costs shown in the table assume the fiber optics adaptation hardware is supplied, and thus do not include that cost. Factors to account for material procurement cost (MPC) and general and administrative cost (G&A), and profit/fee for the prime contractor have not been applied to these dollar estimates.

EMUX Subsystem Implementation

The B-1 EMUX subsystem consists of two independent 1 mb/sec data transfer subsystems, each of which has redundant bus controllers and data links. Figure 4 shows one of these subsystems. For the purposes of power budgeting, EMUX may be considered to consist of four independent buses, each having redundant controllers. The subsystem data transfer requirement is that each controller on a bus must have two-way communication capability with every other LRU on the bus.

Four fiber optics conceptual designs were created for the FOCAP study; new design and retrofit star coupler configuration, and new design and retrofit daisy chain. The retrofit and new-design configurations are identical external to the LRU.

TABLE 6. AMUX, EMUX, AND CITS E-O ADAPTATION INSTALLATION IMPACT
(Obtained from B-1 Suppliers)

Subsystem LRU	Retrofit			New Design		
	Nonrecurring Cost (1976$)	Recurring Cost Per LRU (1976$)	Physical Deltas	Nonrecurring Cost (1976$)	Recurring Cost Per LRU (1976$)	Physical Deltas
CITS Digital/comp	*	*	Volume: no change Weight: +1.5 lb Power: +6.0 w	*	*	Volume: no change Weight: +1.5 lb Power: +6.0 w
CDR	*	*	Volume: no change Weight: +0.25 lb Power: +5.0 w	*		Volume: no change Weight: no change Power: -5 w
EMUX All (except DS-3)	$150,000	$3,800	Volume: no change Weight: +0.5 lb Power: +6 w	$450,000	*	Volume: no change Weight: +0.6 lb Power: +4 w
DS-3	Included in $150,000 above		Length: +0.5 in. Weight: +1.0 lb Power: +6 w			Volume: no change Weight: +0.6 lb Power: +4 w
AMUX CADC	$332,000	$6,700	Length: +1.5 in. Weight: +0.85 lb Power: +5.4 w	$395,000	$5,200	Length: +1.5 in. Weight: +0.55 lb Power: +5.4 w
FISC	$115,000	*	Volume: no change Weight: +0.45 lb Power: +5.4 w	$215,000	*	*
CSS	$37,000	$1,500	Volume: no change Weight: +0.45 lb Power: +5.4 w	$30,000	$1,500	*
VSD	$35,000	$1,500	Volume: no change Weight: +0.45 lb Power: +5.4 w	$39,000	$1,650	*

*Not obtained

Star Coupler Configuration. This configuration uses a star coupler as an optical junction point for all LRU's in an area. A conceptual star coupler configuration for the right-hand primary EMUX data bus is shown in Figure 8. It is typical of the buses in the subsystem. In this figure, LRU's 9200 MX1 through MX4 are the bus controllers. The remainder are primarily data acquisition units and communicate only with the bus controllers. Also shown in this figure are bus terminations labeled GMCPS; these are ground maintenance test points. From a power budgeting standpoint, the bus is divided into multiple segments which communicate via active repeaters in strategically located LRU's. An example of such an LRU is MX24. The repeater repeats all information from either direction on a bit-by-bit basis. Thus, each segment may be considered independent of the remainder of the bus for power budgeting; the only constraint is that cumulative bit error rate for all segments on a bus not exceed the bus requirement.

The link analysis for the star coupler configuration for this bus is shown in Table 7. The table shows the allowable link loss computation, lists the loss elements peculiar to each link in the bus, and tabulates the projected link loss and link margin. The losses associated with loss element are:

Element	Loss (db)
LED/bundle/photodiode	10
Bundle attenuation (per foot)	0.03
Bulkhead connector	4
Y-coupler	7
Star coupler	
5-port	13.5
6-port	14.3

The minimum link margin for this bus for the star coupler concept is 9 db; however, the minimum link margin for one of the other buses in this subsystem is 6 db.

Daisy Chain Configuration. A conceptual daisy chain configuration for the EMUX right-hand primary data bus is shown in Figure 9. In this concept, all information received by an LRU not actively transmitting is repeated on a bit-by-bit basis by the LRU. This concept effectively has an active repeater inside each LRU. The link analysis for the right-hand primary bus in the daisy chain configuration is given in Table 8.

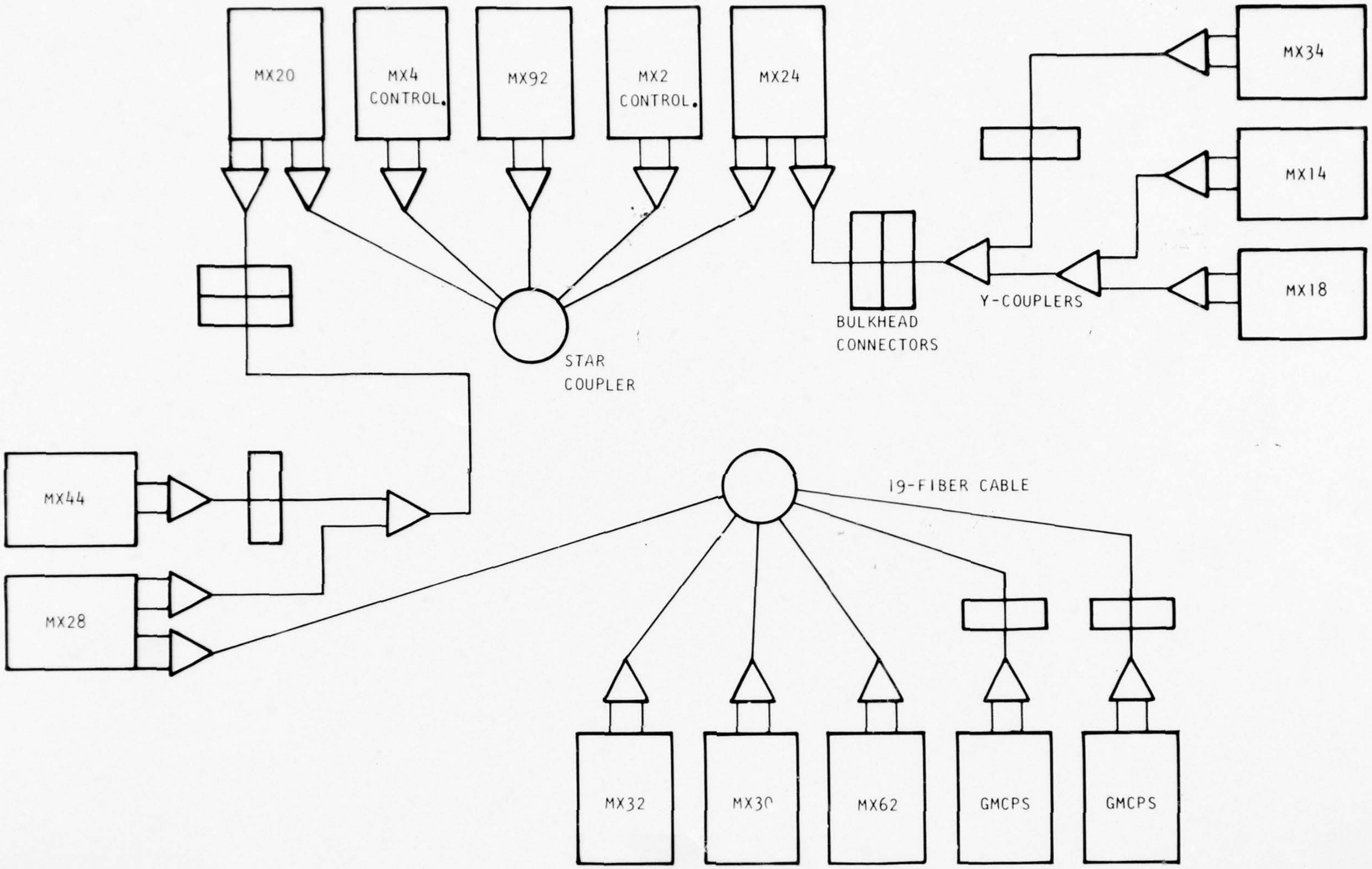


Figure 8. EMUX star coupler configuration.

TABLE 7. LINK ANALYSIS FOR EMUX STAR COUPLER; NEW DESIGN AND RETROFIT

Allowable link loss computation

LED output (2.5 mw)	4 dbm
Receiver sensitivity (variable)	- (-63 dbm)
	67 db
S/N	= 13 db
Allowable link loss	54 db

Link loss and link margin computation

Link From	Link To	Total fiber length (ft)	Number *Y-couplers*	Number bulkhead *connectors*	Star coupler No. of *ports*	Total link loss (db)	Link margin (db)
9200MX2	9200MX24	13	2	-	5	38	16
	9200MX4	12	2	-	5	38	16
	9200MX20	14	2	-	5	38	16
	9200MX92	10	2	-	5	38	16
9200MX24	9200MX34	40	3	2	-	40	14
	9200MX14	64	4	1	-	44	10
	9200MX18	62	4	1	-	44	10
9200MX20	9200MX44	83	3	3	-	45	9
	9200MX28	108	3	2	-	42	12
9200MX28	9200MX32	14	2	-	6	39	15
	9200MX30	12	2	-	6	39	15
	9200MX62	58	2	-	6	40	14
	GMCPS	82	2	1	6	45	9
	GMCPS	48	2	1	6	44	10

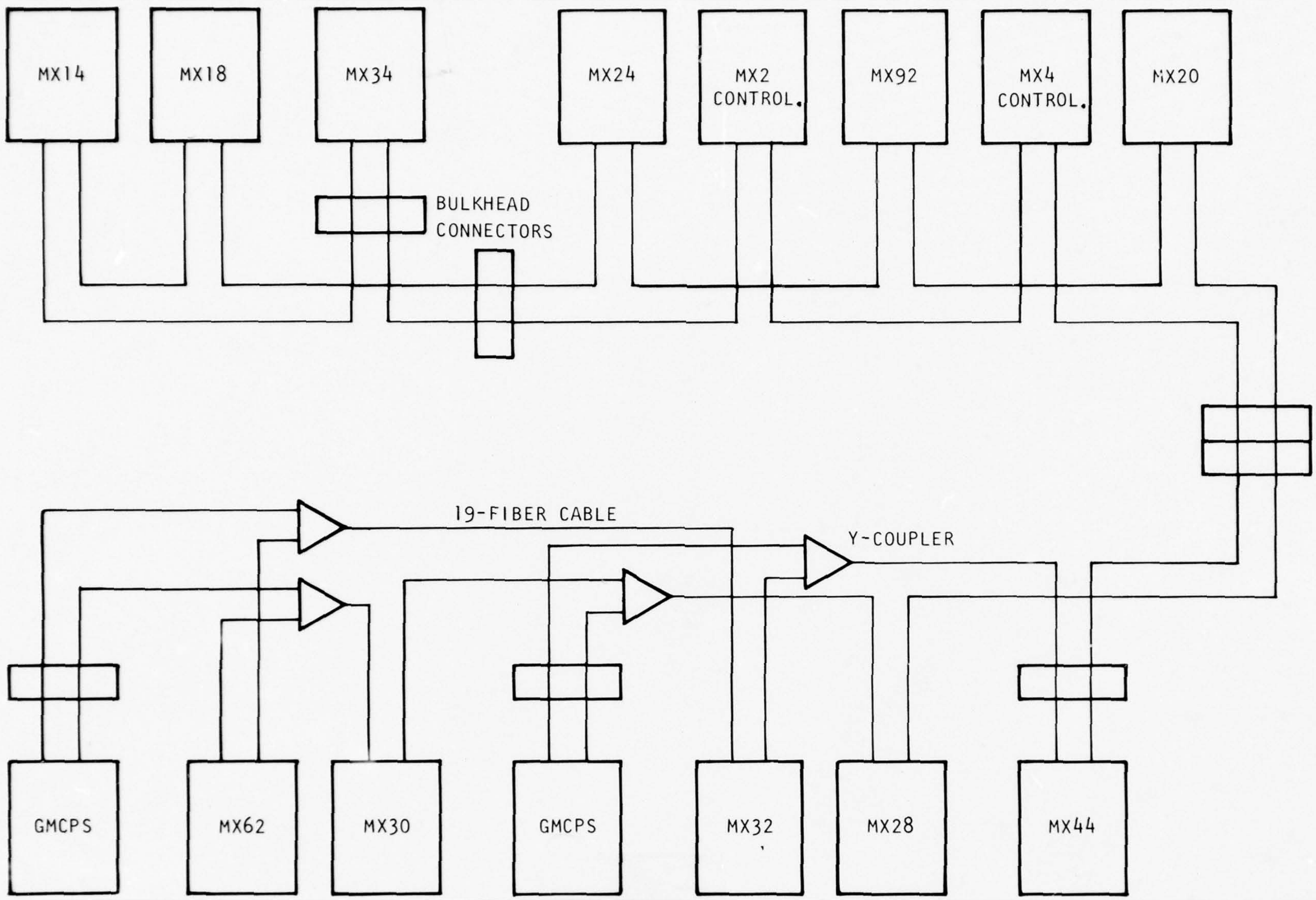


Figure 9. EMUX daisy chain configuration.

TABLE 8. LINK ANALYSIS FOR EMUX DAISY CHAIN; NEW DESIGN AND RETROFIT

Allowable link loss computation

LED output (1 mw)	0 dbm
Receiver sensitivity (fixed)	(-34 dbm)
	34 db

Link loss and link margin computation

Link		Total fiber length (ft)	Number Y-couplers	Number bulkhead connectors	Star coupler No. of ports	Total link loss (db)	Link margin (db)
From	To						
MX44	GMCPS	107	2	1	-	28	6
MX44	MX32	76	1	1	-	23	11
MX32	GMCPS	49	1	1	-	22	12
MX32	MX62	55	-	1	-	19	15
GMCPS	MX30	58	1	1	-	23	11
MX62	MX30	53	-	1	-	19	15
MX30	GMCPS	52	1	1	-	23	11
MX30	MX28	22	-	1	-	18	16
MX28	MX20	107	2	-	-	21	13
MX20	MX92	10	-	-	-	10	24
MX92	MX24	11	-	-	-	10	24
MX24	MX18	33	2	-	-	19	15
MX18	MX14	6	-	-	-	10	24
MX14	MX34	36	1	-	-	15	19
MX34	MX2	37	3	-	-	23	11
MX2	MX4	10	-	-	-	10	24
MX4	MX44	87	3	-	-	25	9

AMUX Subsystem Implementation

The B-1 AMUX subsystem consists of five 1 mb/sec data buses, four of which are two sets of redundant pairs. Two bus controllers having independent functions operate the buses. In the case of one controller failure, the other controller operates all buses in a degraded mode. The fundamental data transfer requirement is similar to that for the EMUX subsystem; each controller must have two-way communication capability with every other LRU on a bus.

Four fiber optics conceptual designs were created for AMUX during the FOCAP study: new design and retrofit star coupler configuration, and new design and retrofit daisy chain. As indicated in the discussion of the E-O interface adaptation for AMUX, the retrofit versions of these configurations require two fiber optic data channels for each communication link; the new design version requires only one.

Star Coupler Configuration. A conceptual star coupler configuration for the AMUX I data bus in the new design mode is shown in Figure 10. This bus is typical of all buses in the subsystem. LRU's 4311A1 and 4311A3 are the bus controllers; LRU's having a designator of the form 4311Pxx are maintenance terminations, growth provisions, or terminations for which the associated LRU may be removed during flight. The bus must be operable having no LRU at these terminations. The retrofit mode would require another set of identical fiber optics components external to the LRU's. The operational concept is identical to that for EMUX. A link analysis for this bus is shown in Table 9. The minimum projected link margin is 6 db.

Daisy Chain Configuration. Figure 11 shows a conceptual daisy chain configuration for the AMUX I data bus in a new design mode. The link analysis for this bus for both retrofit and new design modes is given in Table 10.

CITS Subsystem Implementation

The B-1 CITS subsystem consists of a single 1-mb/sec data bus having a single controller. This controller must have two-way communication with every other LRU on the bus.

The daisy chain configuration was selected for CITS based upon the subsystem having relatively few widely scattered LRU's. Conceptual designs were made in both new design and retrofit modes. The retrofit version requires two fiber optics data channels for each communication link; the new design version requires one. Figure 12 shows a fiber optics design concept for the new

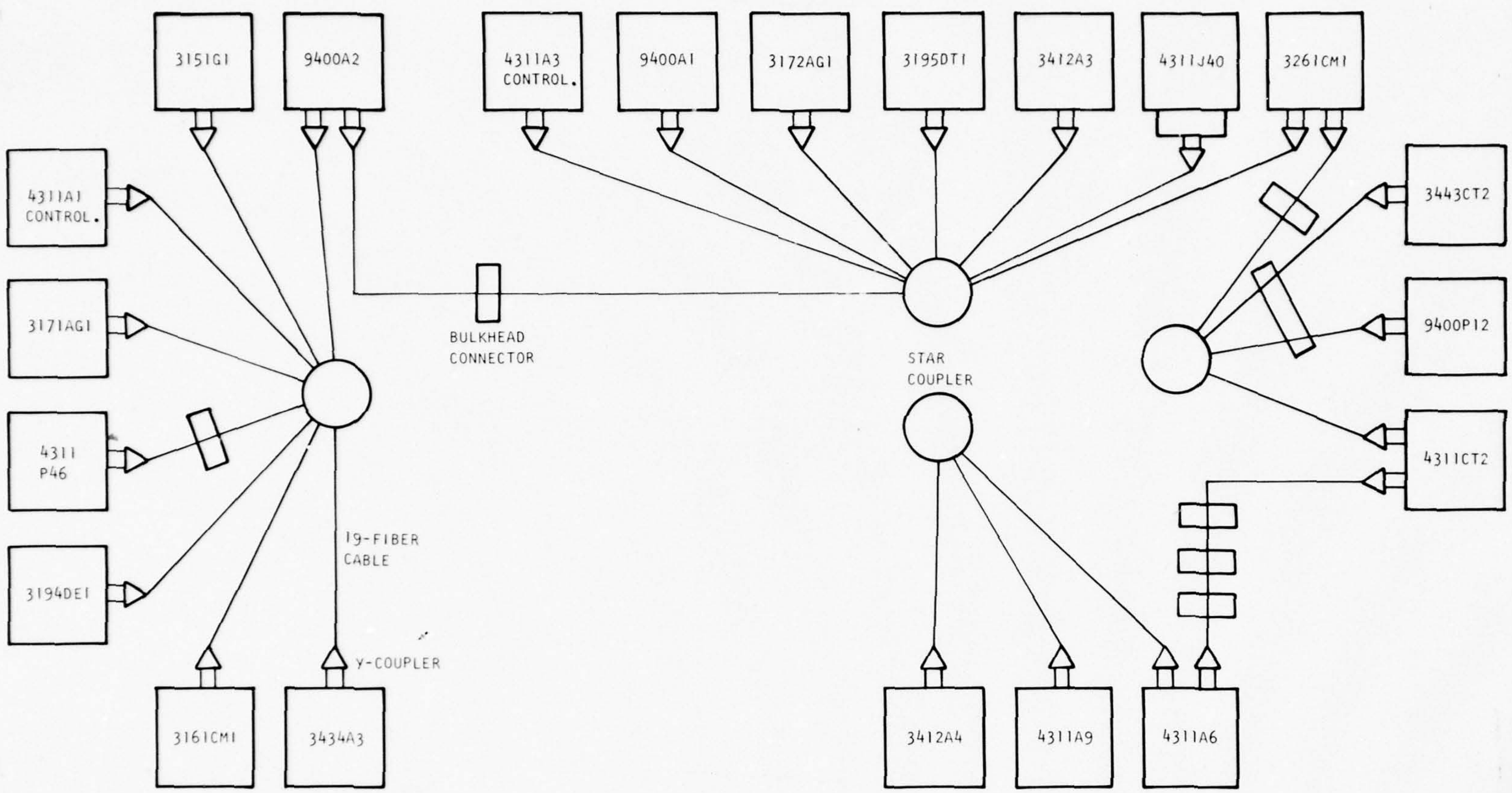


Figure 10. AMUX star coupler configuration.

TABLE 9. LINK ANALYSIS FOR AMUX STAR COUPLER; NEW DESIGN AND RETROFIT

Allowable link loss computation

LED output (3 mw)	6 dbm
Receiver sensitivity (variable)	- (-63 dbm)
	68 db
S/N	-13 db
Allowable link loss	55 db

Link loss and link margin computation

Link From	Link To	Total fiber length (ft)	Number Y-couplers	Number bulkhead connectors	Star coupler No. of ports	Total link loss (db)	Link margin (db)
4311A3	9400A1	7	2	-	8	40	15
	3172A61	6	2	-	8	44	11
	3195DT1	9	2	-	8	44	11
	3412A3	7	2	-	8	44	11
	4311J40	25	2	1	8	44	11
	3261CMI	9	2	-	8	44	11
	9400A2	16	2	1	8	44	11
3261CMI	3443CT2	19	2	2	4	45	10
	9400PL2	18	2	2	4	45	10
	4311CT2	13	2	1	4	41	14
4311CT2	4311A6	28	2	3	-	37	18
4311A6	4311A9	12	2	-	4	37	18
	3412A4	12	2	-	4	37	18
	4311Z1	23	2	1	4	41	14

TABLE 9. LINK ANALYSIS FOR AMUX STAR COUPLER; NEW DESIGN AND RETROFIT (CONCL)

Link		Total fiber length (ft)	Number Y-couplers	Number bulkhead connectors	Star coupler No. of ports	Total link loss (db)	Link margin (db)
From	To						
9400A2	4311540	35	2	2	8	49	6
	3261CMI	19	2	1	8	44	10
	3412A3	17	2	1	8	44	11
	3195PT1	19	2	1	8	44	11
	3172AG1	16	2	1	8	44	11
	9400A1	17	2	1	8	44	11
	4311A3	16	2	1	8	44	11
4311A1	9400A2	8	2	-	8	40	15
	3151G1	8	2	-	8	40	15
	3171AG1	11	2	-	8	40	15
	4311P46	55	2	1	8	45	10
	3434A3	8	2	-	8	40	15
	3161CMI	8	2	-	8	40	15
	3194DT1	10	2	-	8	40	25

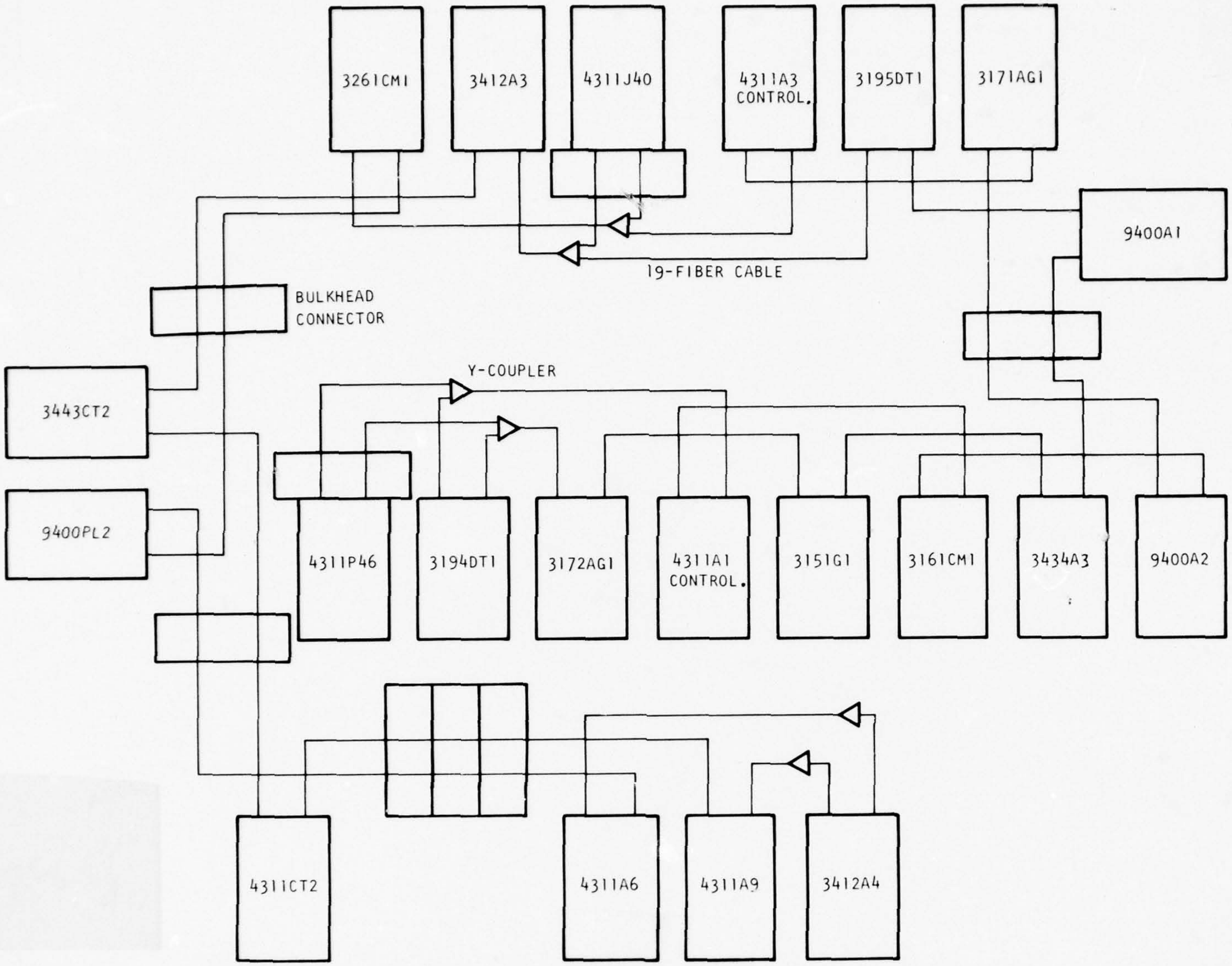


Figure 11. AMUX daisy chain configuration.

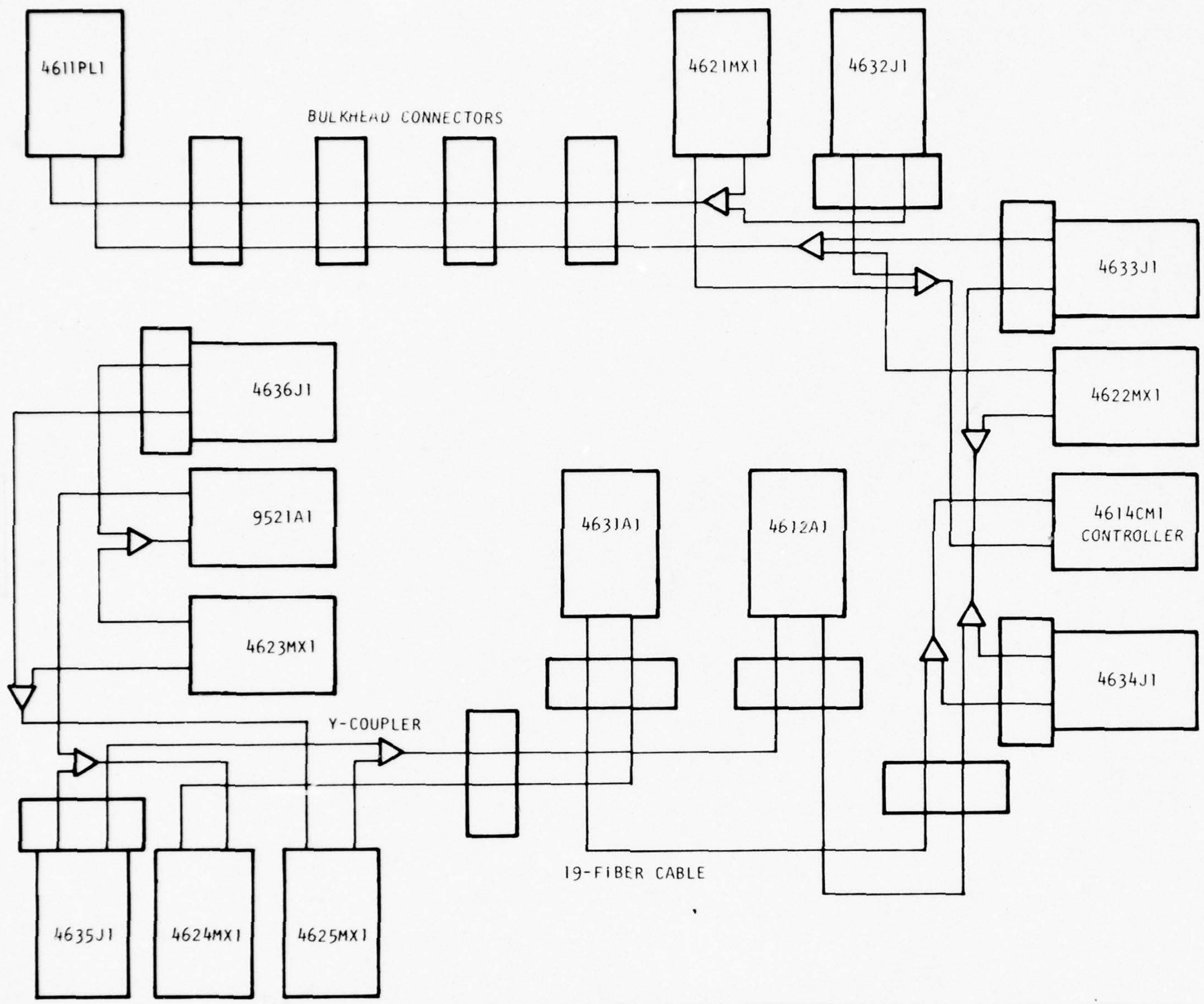


Figure 12. CITS fiber optics design concept.

TABLE 10. LINK ANALYSIS FOR AMUX DAISY CHAIN; NEW DESIGN AND RETROFIT

Allowable link loss computation

LED output (1 mw)	0 dbm
Receiver sensitivity (fixed)	- (-34 dbm)
	34 db

Link loss and link margin computation

Link		Total fiber length (ft)	Number Y-couplers	Number bulkhead connectors	Star coupler No. of ports	Total link loss (db)	Link margin (db)
From	To						
4311A3	3172A61	6	-	-	-	10	24
3172A61	9400A2	19	-	1	-	15	19
9400A2	3161CMI	11	-	-	-	10	24
3161CMI	4311A1	16	-	-	-	10	24
4311A1	3194DT1	8	1	-	-	17	17
4311A1	4311P46	57	1	1	-	23	11
4311P46	3171A61	55	1	1	-	23	11
3194DT1	3171A61	11	1	-	-	17	17
3171A61	3151G1	12	-	-	-	10	24
3151G1	3434A3	11	-	-	-	17	17
3434A3	9400A1	23	-	1	-	15	19
9400A1	3195DT1	7	-	-	-	10	24
3195DT1	3412A3	8	1	-	-	17	17
3412A3	3443CT2	25	-	2	-	19	15
3443CT2	4311CT2	10	-	1	-	14	20
4311CT2	4311A9	29	-	3	-	23	11

TABLE 10. LINK ANALYSIS FOR AMUX DAILY CHAIN; NEW DESIGN AND RETROFIT (CONCL)

Link		Total fiber length (ft)	Number Y-couplers	Number bulkhead connectors	Star coupler No. of ports	Total link loss (db)	Link margin (db)
From	To						
4311A9	3412A4	10	1	-	-	17	17
3412A4	4311A6	10	1	-	-	17	17
4311A6	9400PL2	32	-	4	-	27	7
9400PC2	3261CMI	21	-	2	-	19	15
3261CMI	4311J40	28	1	1	-	18	16
3261CMI	4311A3	7	1	-	-	17	17
4311J40	3412A3	25	1	1	-	22	12

design mode. LRU 4614 CMI is the bus controller. Items 4632J1 through 4636J1 are maintenance test points. All other LRU's may be considered slaves to the controller. The link analyses for both retrofit and new design modes are given in Table 11.

Defensive Subsystem Group (DSG)

General Description

The DSG is an advanced, automated, ration frequency surveillance and electronic countermeasures system (RFS/ECMS) designed to enhance the B-1 penetration through hostile radar environments. The purpose of the DSG digital bus system is the high-speed transmission of data required to assess the electromagnetic environment and control the operation of the RFS/ECMS.

Figure 13 is a block diagram of the baseline DSG digital data buses. A simplified block diagram showing the buses interconnecting the various equipment bays is contained in Figure 14. Data transfer is between 42 LRU's

TABLE 11. LINK ANALYSIS FOR CITS; NEW DESIGN AND RETROFIT

Allowable link loss computation

LED output (1 mw)	0 dbm
Receiver sensitivity (variable)	- (-63 dbm)
	63 dbm
S/N	-13 db
Allowable link loss	50 db

Link loss and link margin computation

Link From	Link To	Total fiber length (ft)	Number Y-couplers	Number bulkhead connectors	Star coupler No. of ports	Total link loss (db)	Link margin (db)
4614CMI	4634J1	14	1	1	-	21	29
4614CMI	4631A1	26	1	2	-	26	24
4631A1	4624MX1	86	0	2	-	21	29
4624MX1	4635J1	11	1	1	-	21	29
4624MX1	9521A1	56	1	0	-	19	31
9521A1	4636J1	36	1	1	-	22	28
9521A1	4623MX1	42	1	0	-	18	32
4636J1	4623MX1	66	1	1	-	23	27
4623MX1	4625MX1	88	1	0	-	20	30
4636J1	4625MX1	151	1	1	-	26	24
4635J1	4612A1	94	1	3	-	32	18
4612A1	4633J1	47	2	3	-	37	13
4634J1	4633J1	36	2	2	-	33	17

TABLE 11. LINK ANALYSIS FOR CITS; NEW DESIGN AND RETROFIT (CONCL)

Link		Total fiber length (ft)	Number Y-couplers	Number bulkhead connectors	Star coupler No. of ports	Total link loss (db)	Link margin (db)
From	To						
4622MX1	4611PL1	72	1	4	-	35	15
4633J1	4611PL1	52	1	5	-	39	11
4611PL1	4621MX1	32	1	4	-	34	16
4611PL1	4632J1	37	1	5	-	38	12
4621MX1	4614CMI	50	1	0	-	19	31
4632J1	4614CMI	45	1	1	-	22	28

interconnected by 31 buses. There are 65 connectors. The bus system may be broken down into five main categories:

		Number of buses
1.	Bidirectional, multiple-stub bus	6
2.	Point-to-point bus	9
3.	Antenna beam steering interface buses	
	a. Pulsewidth modulated analog data	3
	b. Digital data	3
3.	Unidirectional, multiple-stub bus	3
4.	Status evaluation and test (SEAT) buses	7

All digital transmission is via differential drivers (DS 7832) and receivers (DS 7820A).

The bidirectional, multiple-stub bus carries the information between a master LRU and up to five collocated slaves. The maximum length of a cable from a master LRU to the furthest slave of a collocated set is 170 feet. These buses are implemented for a parallel digital data transfer operating at

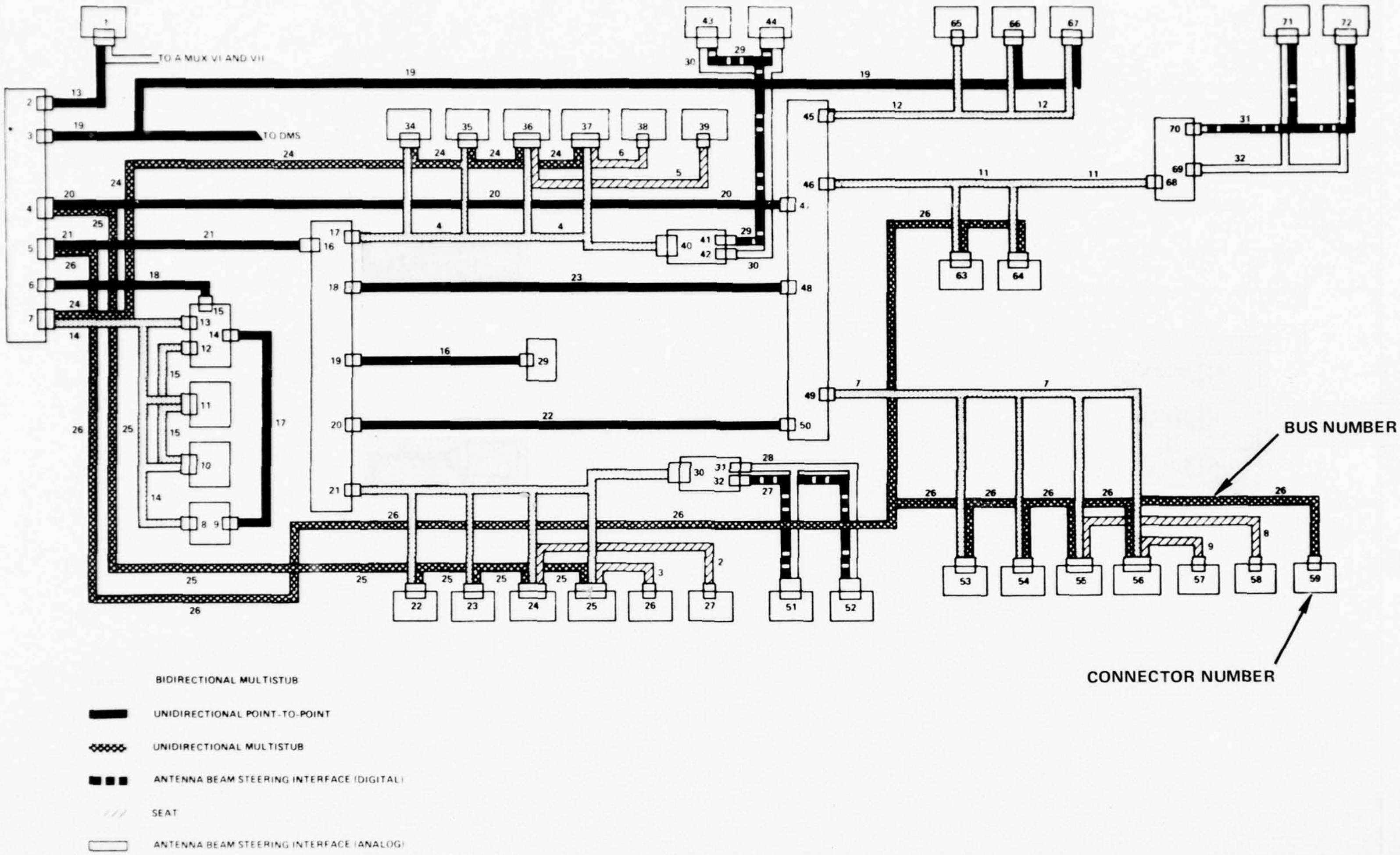
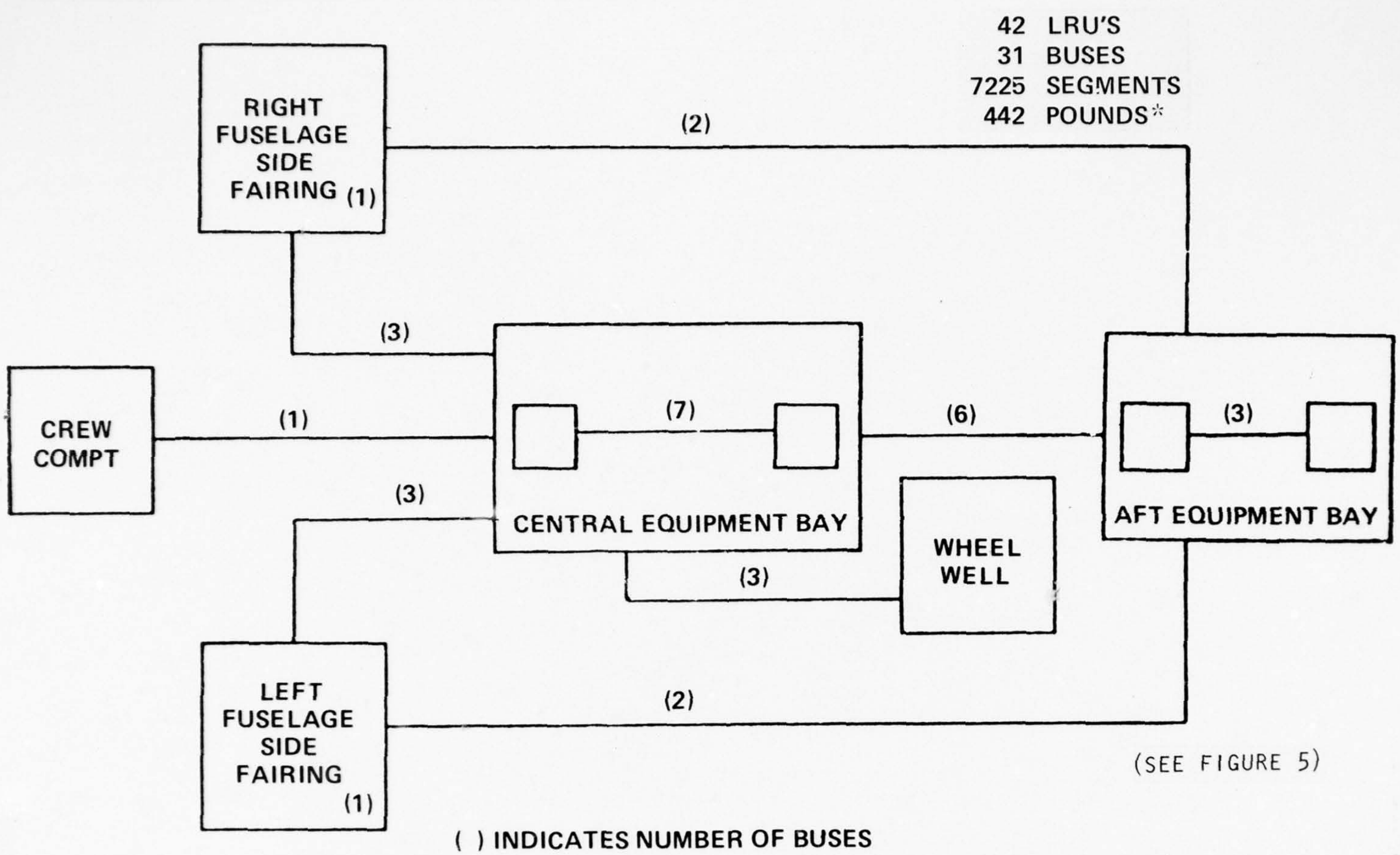


Figure 13. DSG bus system.



* INCLUDES ELECTRICAL WIRING, OVERBRAID, CONDUIT, AND CONNECTORS. DOES NOT INCLUDE LRU'S.

Figure 14. Simplified DSG block diagram.

a peak rate of 1.25 megawords per second, where a word is defined as 16 parallel bits. Additional command and control bits are also required. Data flow is bidirectional and is always between a master and a slave. There is no direct data flow between the slaves. The timing schematic for a bidirectional, multiple-stub bus is shown in Figure 15.

The point-to-point buses are mostly unidirectional buses between two LRU's. The number of channels on the buses varies from 24 to 48. The maximum length of a point-to-point bus is 72 feet.

There are six antenna beam steering interface buses. Three of these buses carry 30 pulse-width modulated (PWM) analog signals each, and three carry 30 digital signals each between a master and the transmitting antenna. The maximum length of a connecting cable is 45 feet.

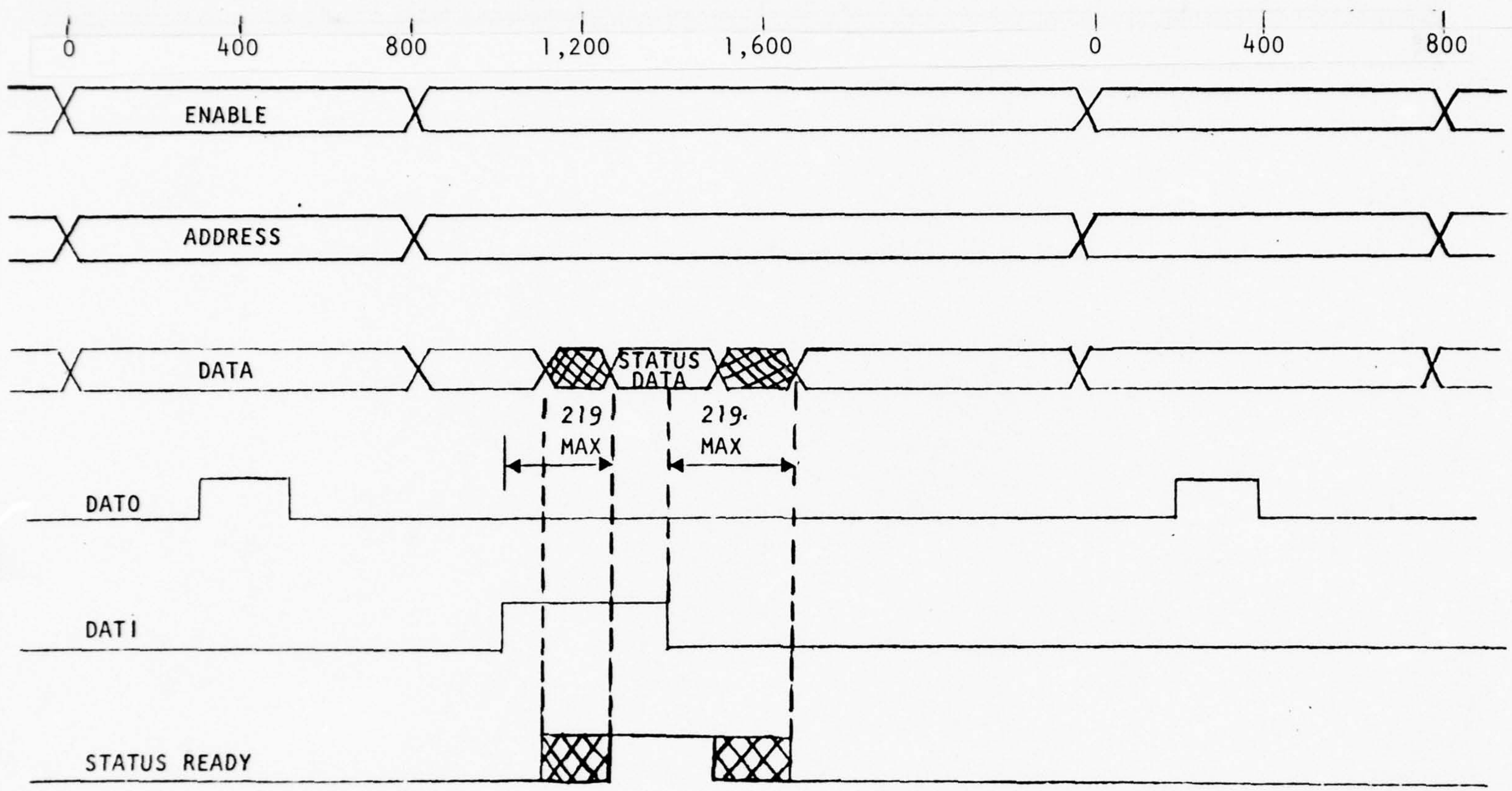
The unidirectional, multiple-stub bus transmits the data over five lines between a master and up to eight slaves. There are four data lines each, and one enable or select line for each slave LRU. The enable line is used to strobe the data lines. The peak rate is 1.25 mb/sec. The maximum length of a cable from a master to a slave is 150 feet.

SEAT buses are point-to-point buses consisting of 33 lines each between a driver and a transmitter. They are short (less than 8 feet) and carry status data in the form of fast-acting discretes rather than a true digital format.

E-O Interface Adaptation

The B-1 DSG data transfer subsystem requires a much higher data transfer rate than any of the other subsystems in the study. The actual data flow rate on some buses is on the order of 25 to 30 mb/sec, and the working data rate of a serially multiplexed data subsystem would be higher, the exact rate depending upon the bus, the multiplexing scheme, and command/response timing requirements. These data rates are presently beyond the capability of the low-risk logic families to implement in a pure serially multiplexed configuration.

Feasibility of High-Speed Logic. A comparison of the operational characteristics of several logic families based on extensive discussions with suppliers and a review of the literature is contained in Table 12. Standard Schottky or ECL both have the speed to serially multiplex the DSG data buses, but both have high LSI fabrication risk and high power consumption. Standard Schottky has the advantage of not requiring level shifters to work with other logic types.



NOTE: ALL RISE AND FALL TIMES 100 NS MAX

Figure 15. Timing schematic for bidirectional multiple-stub bus.

TABLE 12. COMPARISON OF LOGIC TYPES

Logic type	Propagation (nsec/gate)	Clock rate (MHz)	Power dissipation (mw/gate)	System operating speed (MHz)	Speed/power ratio (MHz/mw)	Remarks/risks
CMOS/SOS	8	50	0.3	25	83	Low risk. Present state-of-the art is a system speed of under 20 MHz. Projected 25 MHz is possible in one or 2 years. Easily made in LSI.
Standard TTL	10	35	5	18	3.6	State-of-the-art devices, not easily made into LSI devices.
Low-power Schottky	9.5	45	0.4	23	57.5	State-of-the-art devices. Can be made into LSI due to low-power dissipation. Complexity similar to CMOS/SOS.
Standard Schottky	3	125	10	65	6.5	High risk in fabricating an LSI version of Schottky IC's. On-chip power dissipation is a problem.
ECL	1.5	200	12.5	100	8	Very high risk in fabricating an LSI version of ECL. On-chip power dissipation is a problem. Needs level shifters to work with other logic types.

Of the lower speed logic families listed in Table 12, CMOS/SOS is slightly more attractive for the DSG than low-power Schottky, and both appear to be much better than standard TTL. This conclusion is reached based upon consideration of logic speed capability, power consumption, and technological risk.

Concurrent with the FOCAP program, a B-1 study to develop a plan of action for implementation of fiber optics into the B-1 DSG was conducted by the B-1 Division. During the course of the study, the B-1 DSG data buses and a fiber optics implementation concept were described and forwarded to the industry (Reference 8). The industry was requested to provide development and cost, along with the design data, for interface adapter units. The request was forwarded to Harris, IBM, Singer, Bunker-Ramo, Hughes, Rockwell-Autonetics and ITT. Responses were received from the first five companies. The proposed designs of the interface adapter units varied somewhat, but all suppliers proposed to transmit the data via a hybrid of serial/parallel channels, rather than one single channel in order to utilize low-risk, low-power logic families.

Based upon the data in Table 12 and in concurrence with those systems houses who have studied the DSG data transfer requirements, high-speed logic families are not being used as a baseline in the FOCAP conceptual designs for the DSG. However, the use of high-speed logic is addressed in the cost analysis phase of this study to determine what economic benefits could accrue from its use.

Interface Characteristics. The high data rate requirements of the DSG are accommodated in the retrofit concept using an internal adapter that converts present output parallel data into serial/parallel data to be carried via multiple fiber optics channels. For the redesign concept, the existing parallel multiplexing circuits are replaced by serial/parallel multiplexing circuitry tailored to the specific bus. Again, multiple-fiber optics channels are typically required.

Based upon an analysis of data supplied by various systems houses in implementing the requirements of Reference 8, it was concluded that an interface adapter unit for one bus would have the following typical characteristics:

1. Each adapter would typically multiplex the parallel data into three serial channels. (Each channel operates at speeds up to 25 MHz.) This implies that each adapter would consist of three multiplexers and three demultiplexers.

2. Each multiplexer channel consists of three LSI CMOS/SOS devices plus other components.

3. Each demultiplexer channel consists of three LSI CMOS/SOS devices plus other components.

4. Power dissipation of 0.3 mw/gate at 25 MHz is projected.

The impact to incorporate the serial/parallel multiplexing scheme into the average DSG LRU on a total system basis has been estimated by a study of system-house data. In the retrofit mode, the incorporation of the necessary modules will add 17 cubic inches of volume and 1.7 pounds of weight to each LRU, and will require a power input of 7 watts. In the new design mode, it is estimated that there will be no net physical impact to the LRU.

Fiber Optics Implementation

Each bus in the DSG subsystem is almost unique, from a fiber optics implementation standpoint. Conceptual designs were made for each bus in the subsystem in star coupler and daisy chain general configurations. For simple point-to-point buses, these concepts yield the same design.

A typical fiber optics conceptual design in the daisy chain configuration for one of the multiple-stub buses is shown in Figure 16. This bus requires three channels operating at 18 mb/sec on each channel for data transfer. LRU 6730-1 is the bus controller, and two-way communication between the master and every other LRU must be established. A link analysis for this bus is given in Table 13.

A star coupler concept for the same bus is shown in Figure 17. It also requires three parallel fiber optic links operating at 18 mb/sec. A link analysis for this bus is shown in Table 14. The minimum link margin shown in Table 14 for this bus is 6 db. For two similar buses in the DSG having five slave LRU's in place of the four on this bus, the minimum link margin is 5 db.

8-MUX Subsystem

The low-data rate serially multiplexed subsystems (AMUX, EMUX, and CITS) were investigated first in the FOCAP study because of their relative ease of conversion to fiber optics. All are of uniform Manchester II coding, which is relatively simple to adapt to fiber optics. Early preliminary weight estimates for the fiber-optics versions of these subsystems showed no weight advantage. It became apparent that in a one-for-one, fiber-optics cable for wire replacement, there would be no obvious advantage of fiber optics, and the subsystem would weigh more.

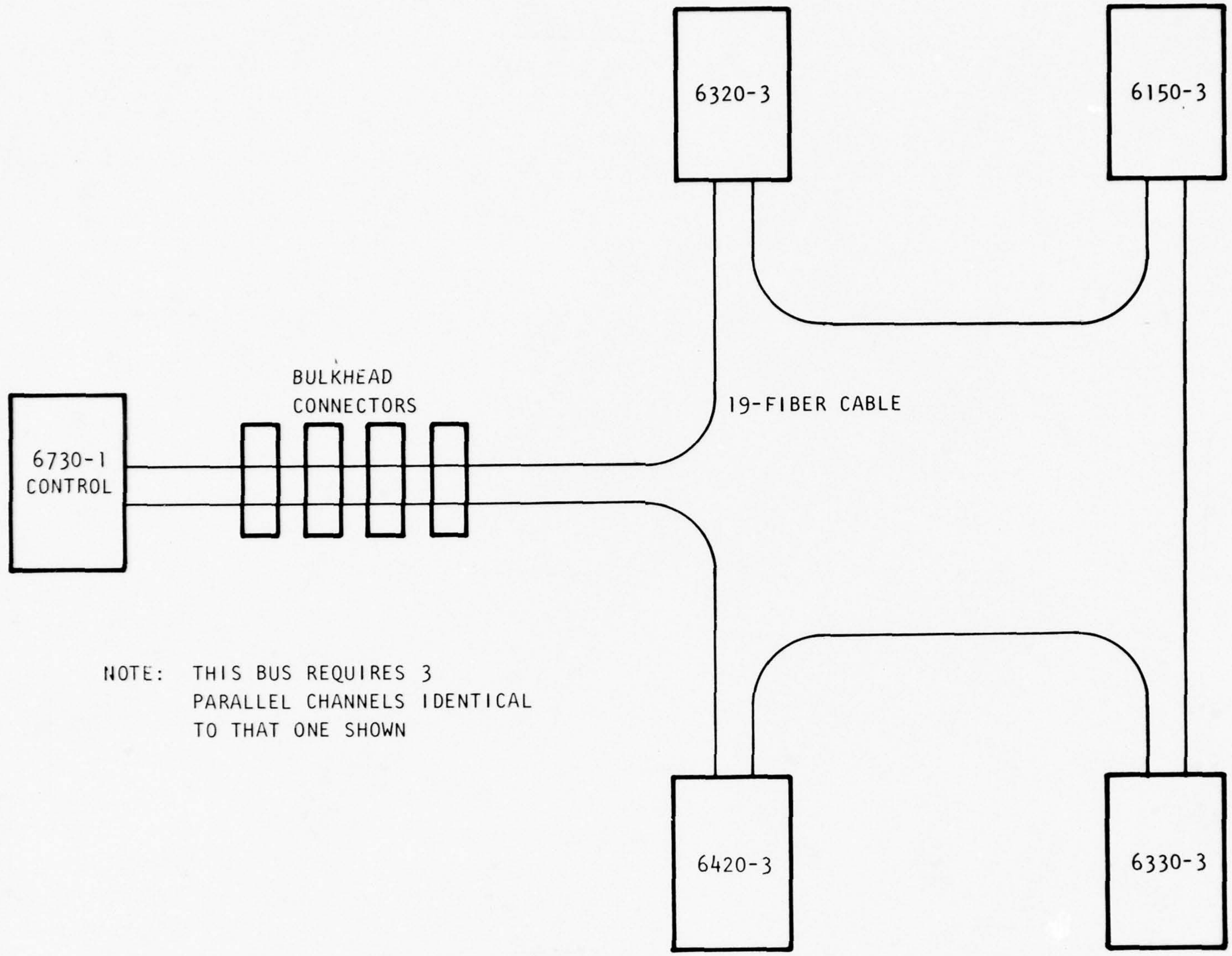


Figure 16. Typical DSG daisy chain configuration.

TABLE 13. LINK ANALYSIS FOR DSG DAISY CHAIN CONFIGURATION

Allowable link loss computation

LED output (2 mw)	3 dbm
Receiver sensitivity (variable)	- (-49 dbm)
	52 db
S/N	-13 db
Allowable link loss	39 db

Link loss and link margin computation

Link		Total fiber length (ft)	Number Y-couplers	Number bulkhead connectors	Star coupler No. of ports	Total link loss (db)	Link margin (db)
From	To						
6730-1	6320-3	140	-	4	-	30	9
6720-3	6150-3	13	-	-	-	10	29
6150-3	6420-3	26	-	-	-	11	28
6420-3	6330-3	13	-	-	-	10	29
6330-3	5730-1	163	-	4	-	31	8

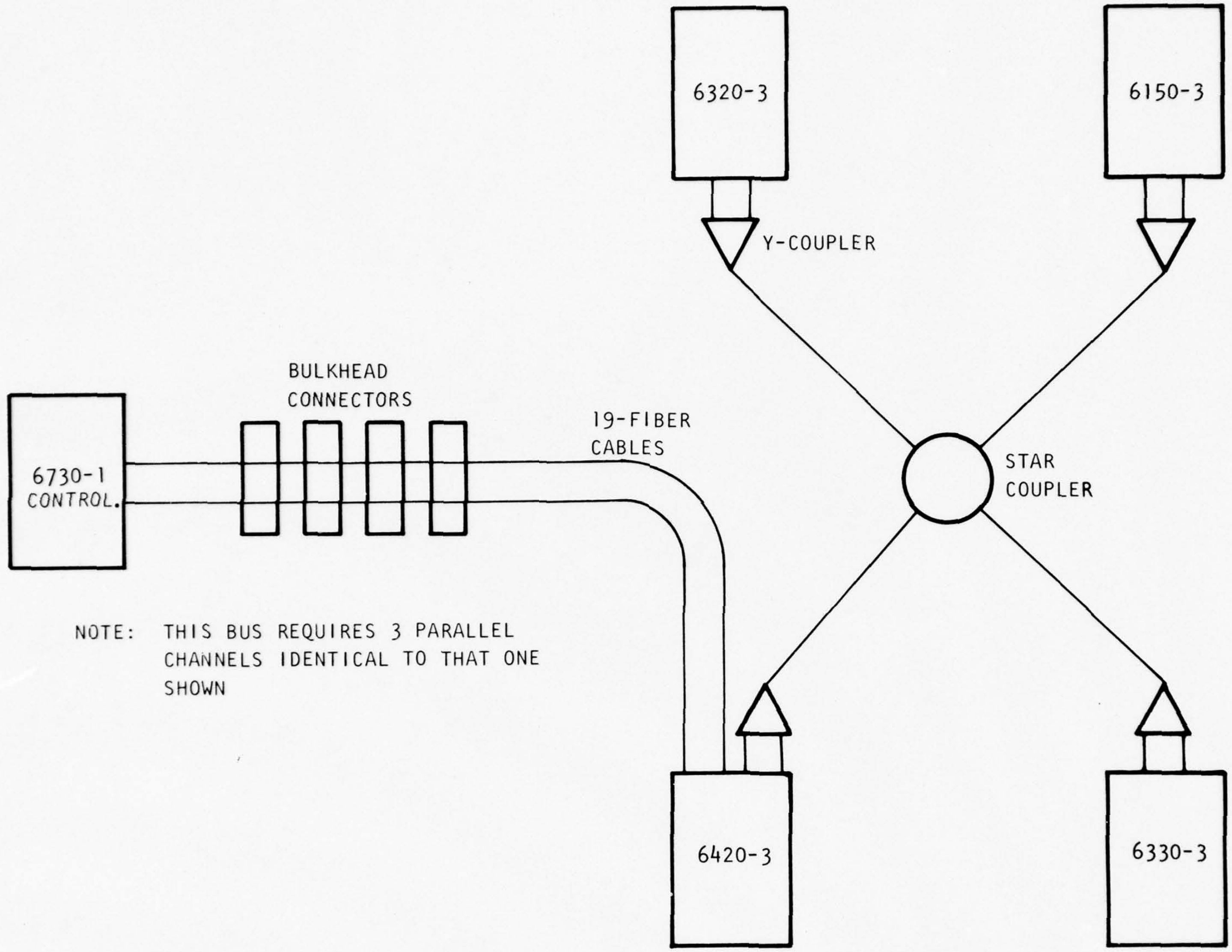


Figure 17. Typical DSG star coupler configuration.

TABLE 14. LINK ANALYSIS FOR DSG STAR COUPLER CONFIGURATION

Allowable link loss computation

LED output (5 mw)	7 dbm
Receiver sensitivity (variable)	- (-49 dbm)
	56 db
S/N	-13 db
Allowable link loss	43 db

Link loss and link margin computation

Link		Total fiber length (ft)	Number Y-couplers	Number bulkhead connectors	Star coupler No. of ports	Total link loss (db)	Link margin (db)
From	To						
6730-1	6320-3	140	-	4	-	30	13
6320-3	6420-3	28	2	-	4	37	6
	6330-3	31	2	-	4	37	6
	6150-3	15	2	-	4	37	6

In light of this knowledge, a straight one-for-one replacement of fibers for wires in the remaining eight subsystems of the FOCAP did not seem worth pursuing. The benefits shown in the DSG had accrued from the use of fiber optics to carry multiplexed data through each fiber bundle at a rate higher than possible with a single wire link. In an attempt to take advantage of the high data rate capability of fiber optics for the eight remaining subsystems, the 8-MUX subsystem was conceived.

The 8-MUX subsystem is a new subsystem design concept investigated in the FOCAP study in an attempt to take advantage of multiplexing/fiber-optics synergistic effects. The 8-MUX subsystem is the conceptual design of a multiplexed configuration for the following subsystems in the B-1 which are not presently multiplexed:

Automatic flight control subsystem

Structural mode control subsystem

Manual flight control subsystem

Mission and traffic control

Flight instruments

Navigation and radars

Stores management and weapon delivery

Crash recorder

Multiplexing Concept

The multiplexing network consists of two redundant control boxes (8CONT1 and 8CONT2) and nine data acquisition units (or terminals) of two types (8DAU1-1 to 8DAU1-7, 8DAU2-1, and 8DAU2-2). In this concept, the controllers and data terminals communicate via a fiber-optics data link; signals from the 246 LRU's of the eight subsystems are fed into the data terminals via wire. The data terminal acts as a signal processor and interface to the fiber-optics data bus.

In order to determine the characteristics of the 8-MUX subsystem, the number of signal terminations was cataloged by subsystem and aircraft area. A total of 29 distinct aircraft area partitions were used. The signal characteristics of each subsystem and the number of terminations in each area were

used to estimate the number of signals of various types (discrete, dc analog, etc) to be handled by the 8-MUX subsystem by area. The 8-MUX subsystem was then defined as the best compromise to minimize the number of data terminal types, minimize the number of wire terminations and lengths, and minimize the data handling capability of each type of data terminal.

The resulting 8-MUX subsystem consists of the two control boxes and nine data terminals located as follows:

Box	Location
8CONT1	Right central equipment bay
8CONT2	Left central equipment bay
8DAU1-1	Left forward equipment bay
8DAU1-2	Right forward equipment bay
8DAU1-3	Forward crew compartment
8DAU1-4	Right central equipment bay
8DAU1-5	Right central equipment bay
8DAU1-6	Left central equipment bay
8DAU1-7	Left central equipment bay
8DAU2-1	Center weapons bay
8DAU2-2	Aft missile bay

The required signal handling capability of the data terminals is as follows:

Terminal type		Signal type: Discrete	Manchester	Dc analog	Ac analog
1	Input/outputs	156	19	6	10
2	Input/outputs	30	22	17	6

The calculated bus data rate for this subsystem is 2 mb/sec. The analysis that resulted in the 2 mb/sec data transmission rate is as follows:

1. The 156 input discretes for type I will be packed into 16-bit words, resulting in 10 words.

2. The 156 output discrete for type I will require 10 words.

3. The 19 inputs and 19 outputs for the type I Manchester signal requires a total of 38 words.

4. The analog signals for type I requires a total of 32 words.

5. The sum results in 90 words.

6. In a similar manner, the type II terminal was analyzed and a 94 word requirement was formulated.

7. The total number of words required to service the whole bus is

   $$(7) \times (90) + (2)\ (94) = 818 \text{ words}$$

8. From discussions with the Flight Controls Group and other groups familiar with the requirements of the eight subsystems, it was determined that a data refresh rate of 100 times a second was required. Thus (818) x (100) = 81,800 words/sec were required.

9. Using the standard B-1 word length of 24 bits per word results in the following:

   $$(81{,}800 \text{ words/sec}) \times (24 \text{ bits/word}) = 1{,}963{,}200 \text{ bits/sec}$$

   Thus a data rate of 2 mb/sec was calculated.

The physical characteristics of the data terminals and control boxes were estimated using existing B-1 AMUX converters, EMUX DS- and DD-type LRU's, CITS data acquisition units, and a formula for calculating the weight of the LRU based on F-111 and B-1 sizing estimates. A factor for projecting weight reduction due to more advanced state-of-the-art devices, and a factor for ac/dc excitation were also employed. Using these existing units as a baseline and making proper modifications, the weight of type I terminal was calculated to be 18 pounds and type II to be 16.6 pounds. A 10% uncertainty factor was added, which resulted in 20 and 18.5 lbs for data terminals, type I and II respectively.

The controller was estimated based on the quantity of integrated circuit components required to perform the controller function. It was estimated that the controller requires the following number of chips:

1.	Memory:	16	
2.	Address generation:	30	
3.	Command generation:	40	Total = 136 chips
4.	I/O:	30	
5.	Miscellaneous:	20	

When this is added to the power supply, the fiber/electrical connectors, and a CITS checkout card, the unit was estimated to utilize 13 modules at 0.25 pound each and a 3.5-pound power supply. Adding 0.5 pound for the connectors will result in a box that weighs approximately 7.25 pounds. The addition of a 10-percent uncertainty factor results in a controller that weighs 8 pounds.

The data terminals are very similar to the B-1 CITS Data Acquisition Units (DAU) and the Flight Instrument Signal Converter (FISC). The power utilized by the DAU's and the FISC's was partitioned to arrive at a power figure for each type of input/output: 0.08 watt was calculated for each discrete I/O, 1 watt for each DC output, 1.5 watts for each DC input, 2 watts for each AC I/O, and 2 watts for each serial digital I/O. The total power was then obtained by multiplication of each type of I/O contained within the data terminal by the above factors. The power for the controller was likewise extrapolated from similar controllers used on the B-1. The results are as follows:

Box	Weight (lb)	Volume (in.^{3})	Power (watts)
Controller	8	280	110
Data terminal - type 1	20	560	156
Data terminal - type 2	18.5	560	160

The volume of those LRU's was extrapolated from data on similar B-1 LRU's.

The control boxes and data terminals are dispersed throughout the vehicle. Because of this, a daisy chain configuration in which each box contains an active repeater is a logical fiber-optics implementation concept.

This configuration suffers a communication breakdown if any one of the LRU's or optical links fail. To counteract this disadvantage, a redundant data bus having two independent data channels (Figure 18) is used. This configuration, in conjunction with the bus operational concept, will allow the bus to operate even if an LRU is completely inoperable. The links serving the two data channels are separately routed throughout the vehicle.

The bus operational concept complements the physical component redundancy. The two control boxes operate the bus. One is designated the master control unit and operates the bus unless it fails; the second control unit monitors the bus and assumes control if the master fails. The control unit not acting as a master always serves its optical repeater function if possible. The control units perform only signal routing functions; no numerical processing is performed. For any unit in the receive mode, the incoming signals on the two buses are independently repeated, with the LRU electronically accepting the first signal to arrive. In the transmit mode, identical signals are transmitted on both buses. As a further precaution, redundant wire signals will be routed to separate data terminals. Using this concept, a bus failure would require at least two LRU failures.

Fiber-Optics Implementation

Figure 19 shows the fiber optics buses for the 8-MUX subsystem. Table 15 contains the link analysis for the 8-MUX fiber-optics concept.

Super-MUX

The super-MUX subsystem is a conceptual design which expands the 8-MUX concept to include all data transfer subsystems in the FOCAP study except for the DSG, including the EMUX, AMUX, CITS, and 8-MUX subsystems. Super-MUX is a complete redesign of these subsystems, combining the controller functions of each of the subsystems into the controller function of super-MUX and their data acquisition and interface function into the same function in super-MUX.

Multiplexing Concept

An analysis of each type of signal for each subsystem was made and resulted in the following:

1. EMUX: 1,920 discrete outputs
   4,528 discrete inputs
   96 digital outputs
   96 digital inputs

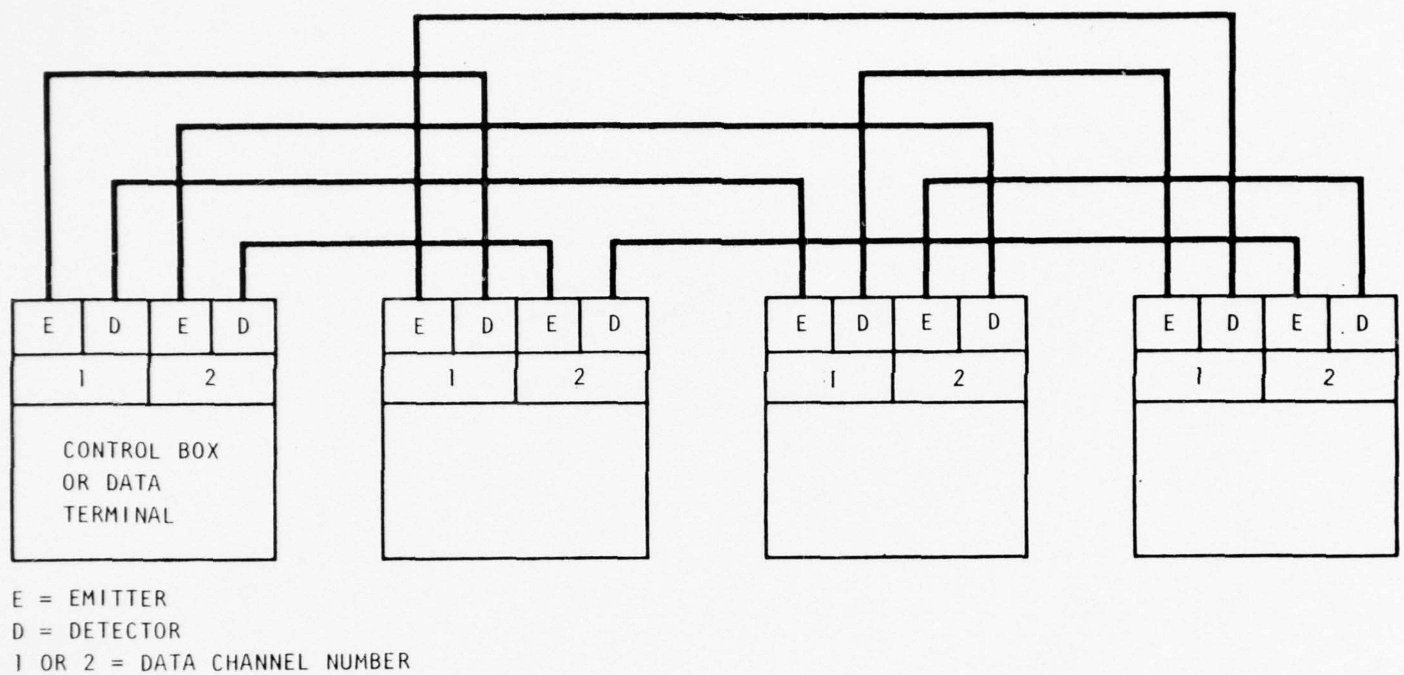


Figure 18. Daisy chain redundant concept.

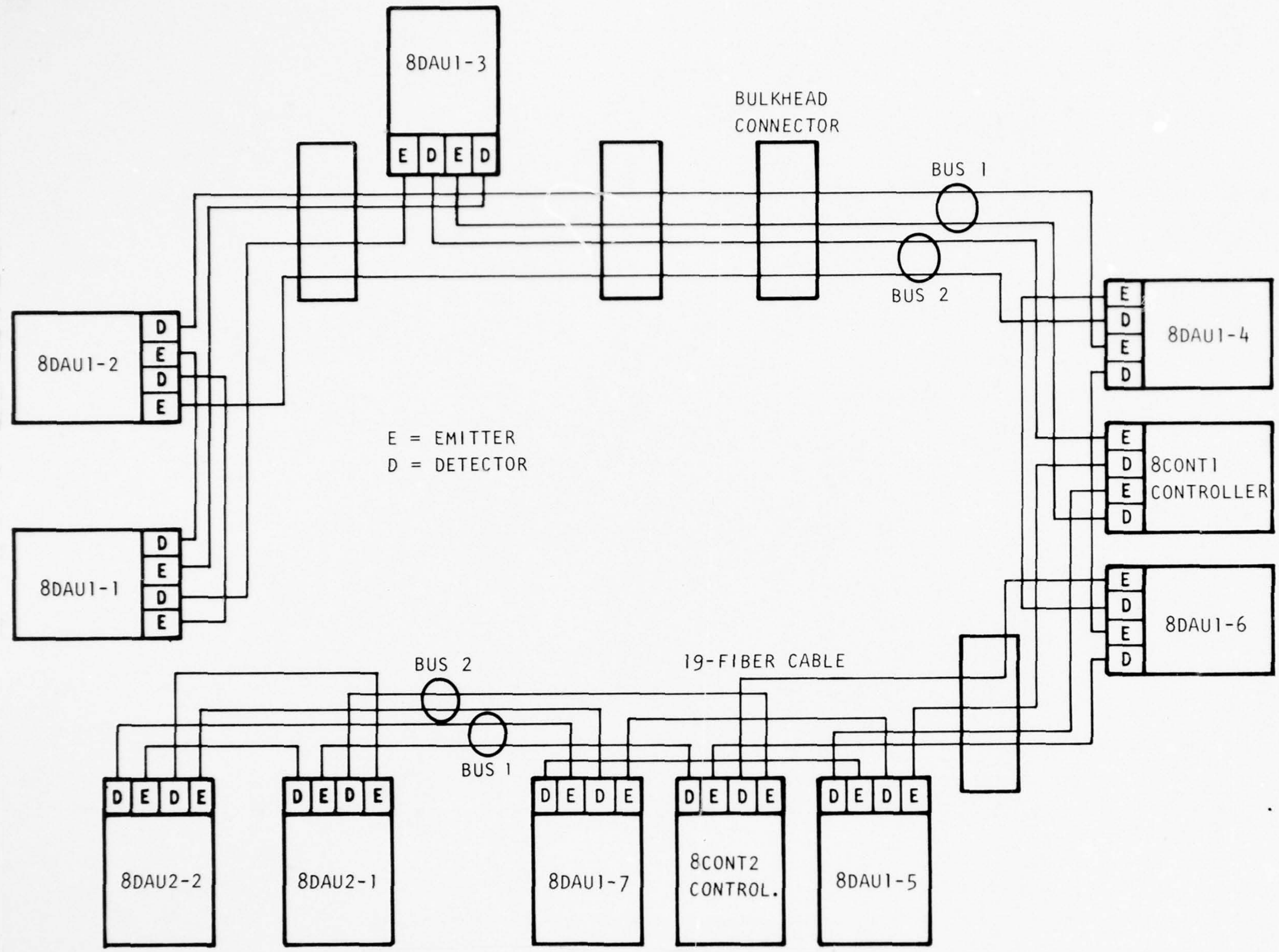


Figure 19. 8-MUX fiber optics buses.

TABLE 15. LINK ANALYSIS FOR 8-MUX

Allowable link loss computation

LED output (1 mw)	0 dbm
Receiver sensitivity (fixed)	- (-34 dbm)
Allowable link loss	34 db

Link loss and link margin computation

Link		Total fiber length (ft)	Number Y-couplers	Number bulkhead connectors	Star coupler No. of ports	Total link loss (db)	Link margin (db)
From	To						
8CONT1	8DAU1-5	2	-	-	-	10	24
8DAU1-5	8DAU1-7	16	-	1	-	14	20
8DAU1-7	8DAU2-1	35	-	-	-	11	23
8DAU2-1	8DAU2-2	35	-	-	-	11	23
8DAU2-2	8CONT2	75	-	-	-	12	22
8CONT2	8DAU1-6	2	-	-	-	10	24
8DAU1-6	8DAU1-4	16	-	1	-	14	20
8DAU1-4	8DAU1-2	37	-	1	-	15	19
8DAU1-2	8DAU1-1	6	-	-	-	10	24
8DAU1-1	8DAU1-3	24	-	1	-	15	19
8DAU1-3	8CONT1	33	-	2	-	19	15

2. CITS: 560 discrete inputs
150 discrete outputs
600 analog inputs
60 digital outputs
60 digital inputs

3. AMUX: 51 digital inputs/outputs

4. 8-MUX: 1,152 discrete inputs
1,152 discrete outputs
177 digital inputs
177 digital outputs
76 dc analog inputs
76 dc analog outputs
82 ac analog inputs
82 ac analog outputs

Combining the aforementioned and using the formula and techniques mentioned in the 8-MUX subsystem design, a system weight of 450 pounds was calculated. It was determined, based on the existing LRU locations and the layouts of the B-1, that 25 of these data acquisition units (DAU) would be required. Thus, each DAU weighs 18 pounds. Standard B-1 estimates for power and volume were applied to size the DAU's:

1. Weight = 18 pounds
2. Power = 144 watts
3. Volume = 560 $in.^3$

For the supercomputer, the capabilities and physical parameters of the existing computers were combined and a 30-percent factor was subtracted due to common I/O, packaging, power supply, motherboard and internal connections, and a single processor concept. Thus, the resultant supercomputer is configured as follows:

1. Weight = 162 pounds
2. Volume = 4,666 $in.^3$
3. Power = 1,253 watts

Since this super-MUX must route data to all existing LRU's at the proper update rate, the bus transfer rate is estimated to be 7 mb/sec. The calculation is 2 mb/sec for AMUX, 2 mb/sec for EMUX, 1 mb/sec for CITS, and 2 mb/sec for 8-MUX. The function of one AMUX bus disappears in this concept.

Fiber-Optics Implementation

A daisy chain conceptual design and a star coupler conceptual design were made for the super-MUX subsystem. The super-MUX daisy chain concept is identical to that for 8-MUX, as shown in Figure 18. A link analysis for this concept is shown in Table 16. In terms of link margin, this must be considered a low-risk design; the worst-case link has a link margin of 15 db.

Figure 20 shows a fiber-optics data bus in the star coupler configuration system for the super-MUX subsystem. The same bus, showing projected equipment locations, is displayed in Figure 21. The super-MUX subsystem will require two such redundant buses, following the general design concept of EMUX, AMUX, and 8-MUX. A link analysis for this concept is given in Table 17.

Evaluation of the link analysis given in Table 17 reveals that this star coupler configuration for super-MUX is somewhat risky. The LED must be driven to a practical limit to achieve a 5 mw output. The 2 db minimum link margin thus achieved is small. An alternate implementation of this same configuration which has lower risk from a link margin standpoint is considered in the cost trade-off phase of the study.

WEIGHT INSTALLATION SUMMARY AND TECHNOLOGICAL RISK ASSESSMENT

The purpose of the studies performed in phase I of the FOCAP study was to provide data for the cost analysis to be performed in phase II. No final conclusions or recommendations were to be made. However, it is instructive to compare the characteristics of the present wire subsystems with a set of possible fiber optics configurations in order to see on a gross basis the changes that could be implemented, and to assess the technological risks assumed in the fiber-optics subsystems designs.

FIBER OPTICS SUBSYSTEMS IMPLEMENTATION WEIGHT IMPACT

Weight Estimation Methods

The basis for the weight change determination was the installation wiring block diagrams of the existing subsystems and the installation block diagrams for the corresponding fiber optics subsystems. From these, items deleted and items added were identified, and the net weight change for the conversion of signal from wire to fiber optic cabling was established. Consistency of results was maintained by using constant weight factors where applicable for component weights of items deleted and items added. Descriptions of the weights methodology are presented in this section.

TABLE 16. LINK ANALYSIS FOR SUPER-MUX DAISY CHAIN CONFIGURATION

Allowable link loss computation

LED output (1 mw)	0 dbm
Receiver sensitivity (fixed)	- (-34 dbm)
Allowable link loss	34 db

Link loss and link margin computation

Link		Total fiber length (ft)	Number Y-couplers	Number bulkhead connectors	Star coupler No. of ports	Total link loss (db)	Link margin (db)
From	To						
SCONT1	SDAU9	3				10	24
SDAU9	SDAU7	20		1		15	19
SDAU7	SDAU3	12		1		14	20
SDAU3	SDAU1	32		2		19	15
SDAU1	SDAU2	6				10	24
SDAU2	SDAU4	26		2		19	15
SDAU4	SDAU6	14		1		14	20
SDAU6	SDAU8	10				10	24
SDAU8	SDAU10	22		1		15	19
SDAU10	SDAU11	3				10	24
SDAU11	SDAU13	16		1		14	20
SDAU13	SCONT2	3				10	24
SCONT2	SDAU12	3				10	24
SDAU12	SDAU17	25				11	23
SDAU17	SDAU19	35				11	23

TABLE 16. LINK ANALYSIS FOR SUPER-MUX DAISY CHAIN CONFIGURATION (CONT.)

Link		Total fiber length (ft)	Number Y-couplers	Number bulkhead connectors	Star coupler No. of ports	Total link loss (db)	Link margin (db)
From	To						
SDAU19	SDAU21	8				10	24
SDAU21	SDAU23	3				10	24
SDAU23	SDAU25	40				11	23
SDAU25	SDAU24	30				11	23
SDAU24	SDAU22	15				10	24
SDAU22	SDAU20	3				10	24
SDAU20	SDAU18	8				10	24
SDAU18	SDAU16	45				11	23
SDAU16	SDAU15	25				11	23
SDAU15	SDAU14	3				10	24
SDAU14	SDAU26	16		1		14	20
SDAU26	SCONT1	3				10	24

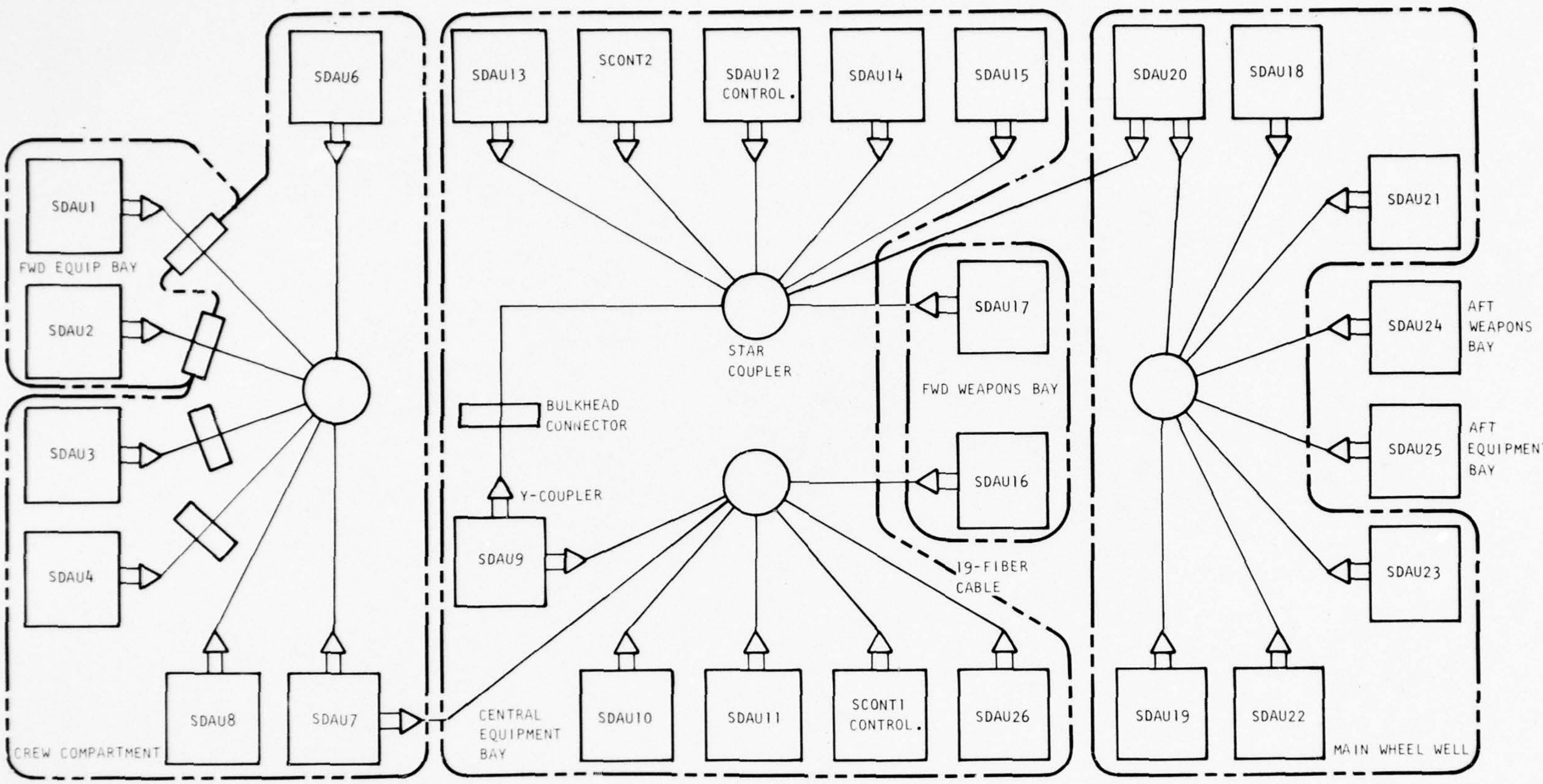
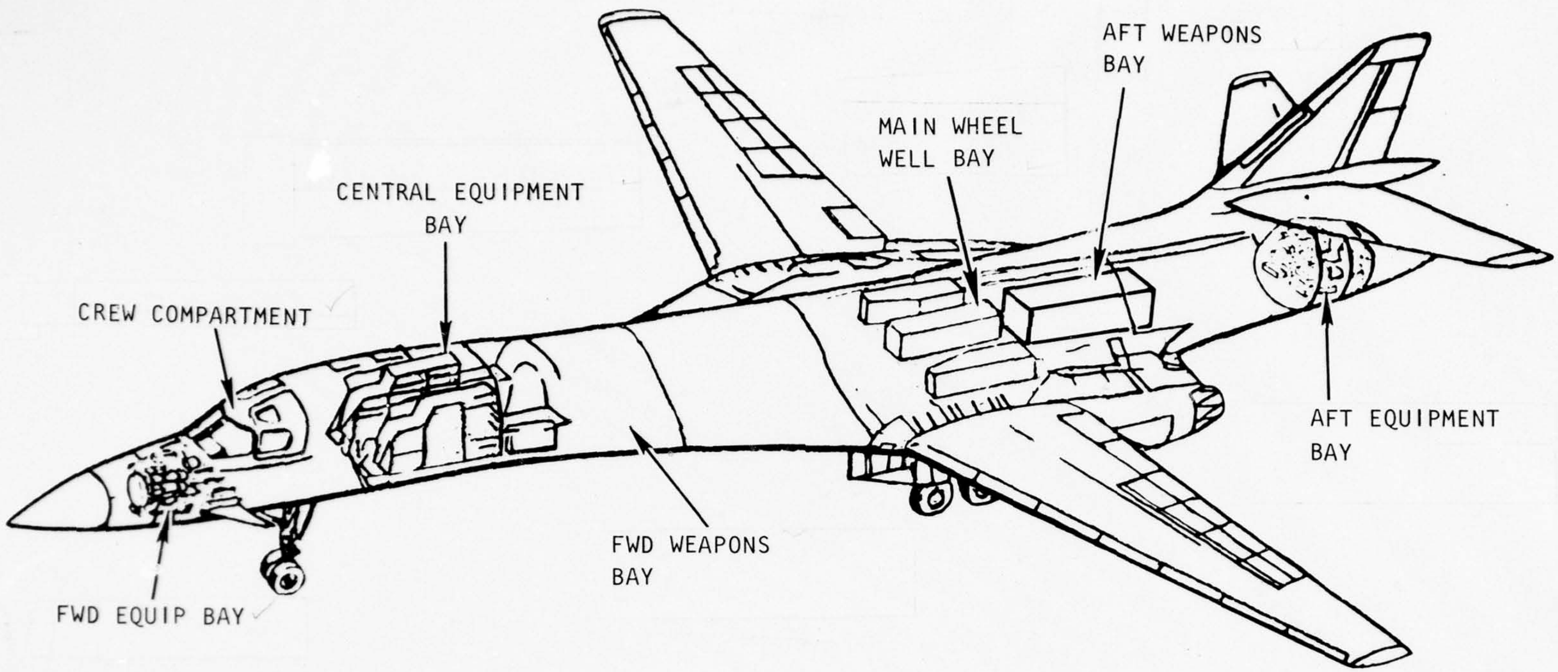


Figure 20. Super-MUX star coupler configuration.



(FIGURE 20 SHOWS THE INTERCONNECTING FIBER OPTIC CABLES.)

Figure 21. Potential Super-MUX equipment locations

TABLE 17. LINK ANALYSIS FOR SUPER-MUX STAR COUPLER CONFIGURATION

Allowable link loss computation

LED output (5 mw)	7 dbm
Receiver sensitivity (variable)	- (-54 dbm)
	61 db
S/N	-13 db
Allowable link loss	48 db

Link loss and link margin computation

Link		Total fiber length (ft)	Number Y-couplers	Number bulkhead connectors	Star coupler No. of ports	Total link loss (db)	Link margin (db)
From	To						
SCONT1	SDAU26	12	2	-	7	39	9
	SDAU11	12	2	-	7	39	9
	SDAU9	14	2	-	7	39	9
	SDAU10	14	2	-	7	39	9
	SDAU16	25	2	-	7	40	8
	SDAU7	18	2	1	7	43	5
SDAU9	SCONT2	22	2	1	8	44	4
	SDAU15	20	2	1	8	44	4
	SDAU12	20	2	1	8	44	4
	SDAU20	68	2	1	8	46	2
	SDAU17	40	2	1	8	45	3
	SDAU14	22	2	1	8	44	4
	SDAU13	22	2	1	8	44	4

TABLE 17. LINK ANALYSIS FOR SUPER-MUX STAR COUPLER CONFIGURATION (CONCL)

Link		Total fiber length (ft)	Number Y-couplers	Number bulkhead connectors	Star coupler No. of ports	Total link loss (db)	Link margin (db)
From	To						
SDAU7	SDAU2	23	2	1	7	44	4
	SDAU1	25	2	1	7	44	4
	SDAU6	14	2	-	7	40	8
	SDAU8	7	2	-	7	40	8
	SDAU3	14	2	1	7	44	4
	SDAU4	14	2	1	7	44	4
SDAU20	SDAU21	8	2	-	8	40	8
	SDAU22	8	2	-	8	40	8
	SDAU23	8	2	-	8	40	8
	SDAU19	13	2	-	8	40	8
	SDAU25	45	2	-	8	41	7
	SDAU24	20	2	-	8	40	8
	SDAU18	13	2	-	8	40	8

Deletions

LRU's. Three subsystems (EMUX, AMUX, and Super-MUX) had LRU's which were present in the wiring implementations removed in the fiber optics concepts. Deleted LRU's of EMUX and AMUX systems were terminal boxes with average weights of 0.1 pound each. Super-MUX consolidates all candidate subsystems, except DSG, into one multiplexed subsystem. Weights of LRU's deleted as a result of this consolidation were obtained from existing equipment lists. In addition, a weight increment equal to 15 percent of deleted LRU weight is removed to account for environmental control, structural, and mounting provisions.

Wiring. Wiring consists of signal-carrying wire, overbraid shielding, and LRU power supply wiring. The signal-carrying wire for all subsystems typically is a two-conductor, twisted, shielded pair, except for the DSG, which uses a wire bundle in a common shield. Twisted, shielded pair weighs 8.7 pounds per 1,000 feet of 24-gage conductor, and 11.6 pounds per 1,000 feet of 22-gage conductor. Each ground wire is assumed to be a 6-inch piece of 24-gage single-conductor wire weighing 2.3 pounds per 1,000 feet.

A deletion was made of a power wire and a circuit breaker for each LRU that was removed due to the incorporation of Super-MUX. The power wires are 20-gage wire in a two-conductor cable, 20 feet long. This cable weighs 8 pounds per 1,000 feet. Circuit breakers weigh an average of 0.1 pound each.

Connectors. Two types of wire connectors are used on the existing systems. They are wire-end connectors that attach to the LRU's, and connectors that route wire through bulkheads.

AMUX, EMUX, and CITS have no change in the number of wire-end LRU connectors. This is because only a small percentage of the wires through the plugs were candidates to be removed. Their removal does not justify plug changes. The high percentage of DSG wire in an end plug which is a candidate for removal reduces the required number of wire-end LRU connectors. This deletion is for "new design" only, as it is impractical to delete these connectors for "retrofit design." Incorporation of Super-MUX and 8-MUX results in an addition of wire-end LRU connectors. The weight of each wire-end LRU connector is an average of 0.163 pound.

Electrical bulkhead connectors reduction is considered for new design only. It is impractical to change these connectors in retrofit designs. Electrical bulkhead connector weight to be deleted was calculated by proportioning the weight of one bulkhead connector by a ratio of the number of bulkhead wire penetrations removed to the number of active connector pins. An average bulkhead connector of these systems has 128 pins, of which 100 are

considered active. A 128-pin complete connector (MS27656 T 25 F35 P receptacle and ES 27467T25 F 35S plug) weighs 0.325 pound.

$$\text{Connector weight deleted} = 0.325 \text{ lb} \times \frac{\text{number of bulkhead penetrations removed}}{100}$$

Conduit and Overbraid. Conduit and overbraid quantity are reduced in the new designs, and equivalent lengths to be removed are specified on the block diagrams of the existing systems. Change of the conduit/overbraid for retrofit design is impractical. The conduit to be deleted is an average of 1-1/4 OD by 0.020-inch molypermalloy tubing which weighs 0.093 pound per foot. The overbraid to be deleted is an average of 3/4-inch-dimeter jacket weighing 0.1536 pound per foot.

Additions

LRU's. For the retrofit systems, a weight increment was added to the existing LRU's to account for modifications to the internal circuitry. The incremental average weight per retrofit LRU is 0.45, 0.40, 0.25, and 1.70 pounds for AMUX, EMUX, CITS, and DSG, respectively. New design LRU's for fiber optics show no weight increase.

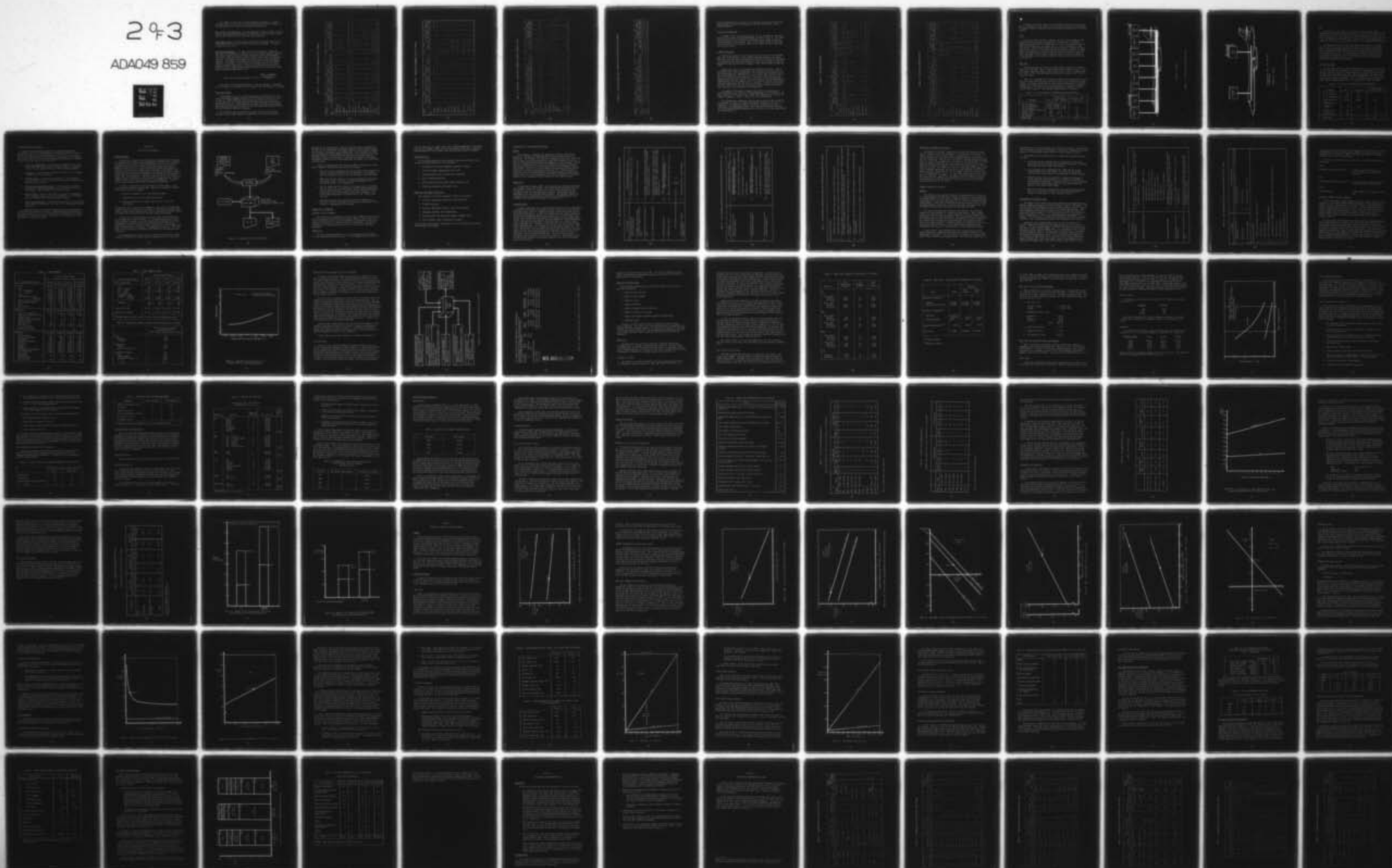
In both retrofit and new design, a 0.05-pound-per-connector allowance was made to account for the addition of LRU fiber optics connectors. The number of connectors to be added is equivalent to the number of LRU fiber optics LRU/panel disconnects as shown on the fiber optics system block diagrams.

The 8-MUX and Super-MUX incorporate additional LRU's. The weights of these are as follows:

LRU	Weight (lb)
8-MUX data acquisition units	
Type I	18
Type II	16
8-MUX control units	8
Super-MUX data acquisition units	18
Super-MUX control units	162

AD-A049 859 ROCKWELL INTERNATIONAL LOS ANGELES CALIF LOS ANGELE--ETC F/G 20/6
FIBER OPTICS COST ANALYSIS PROGRAM (FOCAP).(U)
SEP 77 C C ZELON, J E CASSIDY, R G SHIPLEY F33615-76-C-1260
UNCLASSIFIED NA-77-729 AFAL-TR-77-190 NL

2 of 3
ADA049 859



The weights of these units include LRU/panel receptacles. A weight increment equal to 15 percent of the new LRU weight was added to account for environmental control, structural, and mounting provisions.

Wire, Conduit, and Overbraid. The same methodology and unit weights for wire, conduit, and overbraid were employed for additions in the fiber optics subsystems as for deletions from the existing wiring subsystems.

Fiber Optics Cable. The fiber optics cable used in the FOCAP study is nominally Valtec PC 05-19 Kevlar reinforced with Hytrel sheathing. It weighs 7 pounds per 1,000 feet.

Connectors and Couplers. The same weight and scaling factor assumptions were used for the added wire connectors as for the deleted hardwire connectors. Fiber optics cabling utilizes discrete connectors at LRU's and bulkheads. Fiber optics cable end connectors which attach to LRU's weigh 0.13 pound per connector. The number of end connectors is specified on the system block diagrams. The weight of one complete 20-16P 16 port fiber optics bulkhead connector is 0.26 pound. Only 12 ports are considered active. The total weight of bulkhead connectors in a fiber optics system is obtained by the multiplication of single bulkhead connector weight by the ratio of the total number of bulkhead penetrations to 12.

$$\text{Fiber optics connector weight} = 0.26 \text{ lb} \times \frac{\text{number of bulkhead penetrations}}{12}$$

Fiber optics cable branching utilizes Y- and star couplers. The weight of one Y-coupler is 0.05 pound, and the weight of one star coupler is 0.3 pound.

Subsystems Weights

Weight summaries for the systems evaluated are presented herein. Deletions of candidate component weights of the existing wire systems are given in Table 18. Weight additions for incorporation of the fiber optics are shown in Table 19. Net weight summaries for each system and its options are presented in Table 20. The weights were calculated by applying the methods and assumptions previously described to the systems physical parameters noted on the installation study block diagrams.

The results in Table 20 show that typically there is no substantial difference in the weight change in a subsystem as a function of the fiber

TABLE 18. DELETIONS - EXISTING COMPONENT WEIGHTS (POUNDS)

Subsystem / Item	AMUX				EMUX				CITS		8-MUX	Super-MUX		DSG			
	New Design		Retrofit		New Design		Retrofit							New Design		Retrofit	
	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	New Design	Retrofit		Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain
LRU's																	
Data link terminator boxes	0.4	0.4	0.4	0.4	6.2	6.2	6.2	6.2	--	--	--	6.6	6.6	--	--	--	--
Major equipment items	--	--	--	--	--	--	--	--	--	--	--	801.1	801.1	--	--	--	--
Equip. inst. provisions	--	--	--	--	--	--	--	--	--	--	--	120.2	120.2	--	--	--	--
Hardware																	
Signal carrying wire	9.3	9.3	9.3	9.3	10.9	10.9	10.9	10.9	2.5	2.5	276.5	299.2	299.2	345.5	345.5	345.5	345.5
Ground wires	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.1	0.1	6.4	7.3	7.3	0.4	0.4	0.4	0.4
Power supply wires	--	--	--	--	--	--	--	--	--	--	--	6.4	6.4	--	--	--	--
Circuit breakers	--	--	--	--	--	--	--	--	--	--	--	4.0	4.0	--	--	--	--
Connectors																	
Wire end LRU connectors	--	--	--	--	--	--	--	--	--	--	--	--	--	12.4	12.4	--	--
Bulkhead connectors	0.1	0.1	--	--	0.1	0.1	--	--	Neg	--	4.1	4.3	4.3	7.2	7.2	--	--
Conduit & overbraid																	
Conduit	0.6	0.6	--	--	0.8	0.8	--	--	0.2	--	17.6	19.2	19.2	20.5	20.5	--	--
Overbraid	1.7	1.7	--	--	2.2	2.2	--	--	0.5	--	49.8	54.2	54.2	56.1	56.1	--	--
Total deletions	12.5	12.5	10.1	10.1	20.6	20.6	17.5	17.5	3.3	2.6	354.4	1,322.5	1,322.5	442.1	442.1	345.9	345.9

TABLE 19. ADDITIONS - FIBER OPTICS COMPONENT WEIGHTS (POUNDS)

Subsystem / Item	AMUX				EMUX				CITS		8-MUX	Super-MUX		DSG			
	New Design		Retrofit		New Design		Retrofit							New Design		Retrofit	
	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	New Design	Retrofit		Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain
LRU's																	
Retrofit increment	--	--	12.2	12.2	--	--	10.4	10.4	--	2.5	--	--	--	--	--	71.4	71.4
Fiber-optics connectors	2.7	2.7	2.7	2.7	1.9	1.9	1.9	1.9	0.9	0.9	--	--	--	3.9	2.9	3.9	2.9
8-MUX DAU type I	--	--	--	--	--	--	--	--	--	--	126.0	--	--	--	--	--	--
8-MUX DAU type II	--	--	--	--	--	--	--	--	--	--	33.2	--	--	--	--	--	--
8-MUX control units	--	--	--	--	--	--	--	--	--	--	16.0	--	--	--	--	--	--
Super-MUX SDAU	--	--	--	--	--	--	--	--	--	--	--	450.0	450.0	--	--	--	--
Super-MAX control units	--	--	--	--	--	--	--	--	--	--	--	324.0	324.0	--	--	--	--
Equip. inst. provisions	--	--	--	--	--	--	--	--	--	--	26.3	116.1	116.1	--	--	--	--
Hardwire																	
Signal carrying wire	--	--	--	--	--	--	--	--	--	--	166.8	153.1	153.1	--	--	--	--
Ground wires	--	--	--	--	--	--	--	--	--	--	6.1	6.0	6.0	--	--	--	--
Power supply wires	--	--	--	--	--	--	--	--	--	--	1.8	4.5	4.5	--	--	--	--
Circuit breakers	--	--	--	--	--	--	--	--	--	--	1.1	2.8	2.8	--	--	--	--

TABLE 19. ADDITIONS - FIBER OPTICS COMPONENT WEIGHTS (POUNDS) (CONCL)

Subsystem / Item	AMUX				EMUX				CITS		8-MUX	Super-MUX		DSG			
	New Design		Retrofit		New Design		Retrofit							New Design		Retrofit	
	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	New Design	Retrofit		Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain
Conduit & overbraid																	
Conduit	--	--	--	--	--	--	--	--	--	--	9.8	8.7	8.7	--	--	--	--
Overbraid	--	--	--	--	--	--	--	--	--	--	27.1	24.1	24.1	--	--	--	--
Fiber optics cable	8.4	16.1	16.8	32.2	8.1	14.7	8.1	14.7	4.2	8.4	3.9	5.7	6.2	46.9	47.6	46.9	47.6
Connectors																	
Wire end LRU connectors	--	--	--	--	--	--	--	--	--	--	5.5	5.9	5.9	--	--	--	--
Harness & bulk-head connectors	--	--	--	--	--	--	--	--	--	--	0.7	0.7	0.7	--	--	--	--
Fibre optics end LRU connectors	6.4	6.4	6.4	6.4	4.9	4.9	4.9	4.9	2.2	2.2	2.9	7.3	7.3	9.8	7.2	9.8	7.2
Fiber optics bulkhead connectors	0.2	0.5	0.4	1.0	Neg	0.4	Neg	0.4	0.1	0.3	0.2	0.3	0.4	4.2	3.8	4.2	3.8
Couplers																	
'Y' couplers	4.0	1.7	8.1	3.4	3.7	0.7	3.7	0.7	0.5	1.0	--	3.0	--	7.0	--	7.0	--
Star couplers	4.8	--	9.0	--	2.4	--	2.4	--	--	--	--	2.4	--	5.7	--	5.7	--
Total additions	26.5	27.4	55.6	57.9	21.0	22.0	31.4	33.0	7.9	15.3	427.4	1,114.6	1,109.8	77.5	61.5	148.9	132.9

TABLE 20. NET WEIGHT CHANGE DUE TO FIBER OPTICS SYSTEM INSTALLATION (POUNDS)

Subsystem / Item	AMUX				EMUX				CITS		8-MUX	SUPERMUX		DSG			
	New Design		Retrofit		New Design		Retrofit							New Design		Retrofit	
	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	New Design	Retrofit		Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain
Delections	12.5	12.5	10.1	10.1	20.6	20.6	17.6	17.5	3.3	2.6	354.4	1,322.5	1,322.5	443.0	443.0	346.8	346.8
Additions	26.9	27.8	56.2	58.6	21.0	22.6	31.4	33.0	7.9	15.3	427.4	1,114.8	1,109.1	79.1	62.5	150.5	133.9
Net change	+14.4	+15.3	+46.1	+48.5	+0.4	+2.0	+13.9	+15.5	+4.6	12.7	+73.0	-207.7	-212.6	-363.9	-380.5	-196.3	-212.9

optics configuration (daisy-chain or star coupler); however, the new design implementation is always significantly better than the retrofit, from a weight standpoint.

INSTALLATION COMPARISON

A summary of the installation features for all subsystems in the FOCAP study for the present wiring implementation is shown in Table 21. The installation features for the fiber optics implementation are shown in Table 22. The determination of the economic value of fiber optics in these subsystems is performed in the cost analysis phase of this study, but the results thus far merit discussion.

1 MB/SEC Subsystems

There is no obvious overall savings that fiber optics has for the AMUX, EMUX, and CITS subsystems. Each of these subsystems operates at 1 mb/sec data rate, and fiber optics implementation consists essentially of replacement of each twisted, shielded pair segment by a fiber optics segment in the new design mode, and two fiber optics segments in the retrofit mode for AMUX and CITS.

None of the total of 10 configurations studied saves weight. The new design EMUX fiber optics configurations are essentially the same weight as the corresponding wire implementation. This results from the removal of the data link terminators, which serve as electrical bus taps, from the subsystem for the fiber optics configuration. In general, the new design star coupler fiber cable total weight is less than that for the corresponding wire implementation, but the required fiber optics couplers push the fiber optics subsystem weight above that for the wire subsystem. The daisy chain configurations require more fiber cable weight for both new design and retrofit modes than do the corresponding wire configurations.

The number of fiber optics segments required for each subsystem is almost universally less than the corresponding number of wire segments. The only exception is the retrofit star coupler AMUX configuration, in which the number of segments is equal to that of the wire configuration.

Even though these subsystems serve the entire aircraft, their total subsystem weight is small, the largest being about 20 pounds in the wire configuration. The amount of conduit and overbraid allocatable to these subsystems is correspondingly small. Their low physical density precludes the use of higher bandwidth capabilities of fiber optics to lower total weight on a subsystem basis.

TABLE 21. WIRE SUBSYSTREMS DATA

Subsystem / Item	AMUX				EMUX				CITS			Super-MUX		DSG			
	New Design		Retrofit		New Design		Retrofit							New Design		Retrofit	
	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	New Design	Retrofit	8-MUX	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain
No. 22 wire (ft)	--	--	--	--	--	--	--	--	--	--	27,500	27,500	27,500	--	--	--	--
No. 22 segments (No.)	--	--	--	--	--	--	--	--	--	--	4,975	4,975	4,975	--	--	--	--
No. 24 wire (ft)	2,300	2,300	2,300	2,300	2,700	2,700	2,700	2,700	600	600	30,050	35,650	35,650	79,600	79,600	79,600	79,600
No. 24 segments (No.)	540	540	540	540	740	740	740	740	140	140	6,060	7,480	7,480	7,225	7,225	7,225	7,225
Overbraid (ft)	11	11	--	--	14.4	14.4	--	--	3.2	--	325	353.6	353.6	365.0	365.0	--	--
Conduit (ft)	6.6	6.6	--	--	8.6	8.6	--	--	1.9	--	189.1	206.2	206.2	220.0	220.0	--	--
Bulkhead connectors (No.)	0.2	0.2	--	--	0.3	0.3	--	--	0.1	--	12.2	12.8	12.8	22.0	22.0	--	--
End connectors (No.)	--	--	--	--	--	--	--	--	--	--	--	--	--	73.0	73.0	--	--
Major LRU deletions (No.)	--	--	--	--	--	--	--	--	--	--	--	36	36	--	--	--	--
Data link terminators (No.)	4	4	4	4	62	62	62	62	--	--	--	66	66	--	--	--	--
Total subsystem wt (lb)	12.5	12.5	10.1	10.1	20.6	20.6	17.5	17.5	3.3	2.6	354.4	1,322.5	1,322.5	442.1	442.1	345.9	345.9

TABLE 22. FIBER OPTICS SUBSYSTEMS DATA

Subsystem / Item	AMUX				EMUX				CITS		8-MUX	Super-MUX		DSG			
	New Design		Retrofit		New Design		Retrofit							New Design		Retrofit	
	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	New Design	Retrofit		Star Coupler	Daisy Chain	Star Coupler	Daisy Chain	Star Coupler	Daisy Chain
Fiber (ft)	1,200	2,300	2,400	4,600	1,150	2,100	1,150	2,100	600	1,200	550	808	882	6,700	6,800	6,700	6,800
Fiber segments (No.)	270	180	540	360	220	115	220	115	40	80	32	192	76	690	390	690	390
No. 24 wire (ft)	--	--	--	--	--	--	--	--	--	--	41,000	37,800	37,800	--	--	--	--
No. 24 segments (No.)	--	--	--	--	--	--	--	--	--	--	10,600	10,400	10,400	--	--	--	--
Overbraid (ft)	--	--	--	--	--	--	--	--	--	--	176.2	157	157	--	--	--	--
Conduit (ft)	--	--	--	--	--	--	--	--	--	--	105.6	94	94	--	--	--	--
Y-couplers (No.)	79	34	162	68	73	14	73	14	10	20	--	60	--	140	--	140	--
Star couplers (No.)	16	--	30	--	8	--	8	--	--	--	--	8	--	19	--	19	--
Fiber bulkhead conn (No.)	0.8	1.9	1.6	3.8	0.7	1.4	0.7	1.4	0.5	1.0	0.9	1.0	1.6	16.0	14.5	16.0	14.5
Wire bulkhead conn (No.)	--	--	--	--	--	--	--	--	--	--	2.2	2.2	2.2	--	--	--	--
Fiber end conn (No.)	49	49	49	49	38	38	38	38	17	17	22	54	54	75	55	75	55
Wire end conn (No.)	--	--	--	--	--	--	--	--	--	--	34	36	36	--	--	--	--
LRU additions (No.)	--	--	--	--	--	--	--	--	--	--	11	27	27	--	--	--	--
LRU modifications (No.)	27	27	27	27	26	26	26	26	10	10	--	--	--	42	42	42	42
Total subsystem wt (lb)	26.5	27.4	55.6	57.9	21.0	22.0	31.4	33.0	7.9	15.3	427.4	1,114.8	1,109.8	77.5	61.5	148.9	132.7

In summary, it appears that for these 1-mb/sec subsystems, fiber optics offers no advantage of the present wire implementation unless the lower number of segments typically employed becomes an overriding consideration in the cost analysis.

8-MUX

As was previously explained, 8-MUX was conceived in an attempt to take advantage of the high data rate capabilities of fiber optics to handle signals not already carried by EMUX, AMUX, or CITS. The resulting subsystem does not look promising, even making use of a 2 mb/sec capability of the fiber optics. The aircraft weight would be increased by 73 pounds by employment of this concept. A total of 11 new LRU's would be required. The total number of segments (wire plus fiber optics) would be reduced by about 4 percent, from about 11,000 to about 10,600, and the total data link footage in the subsystems covered would be reduced by about 25 percent, from 57,550 to 41,550 feet.

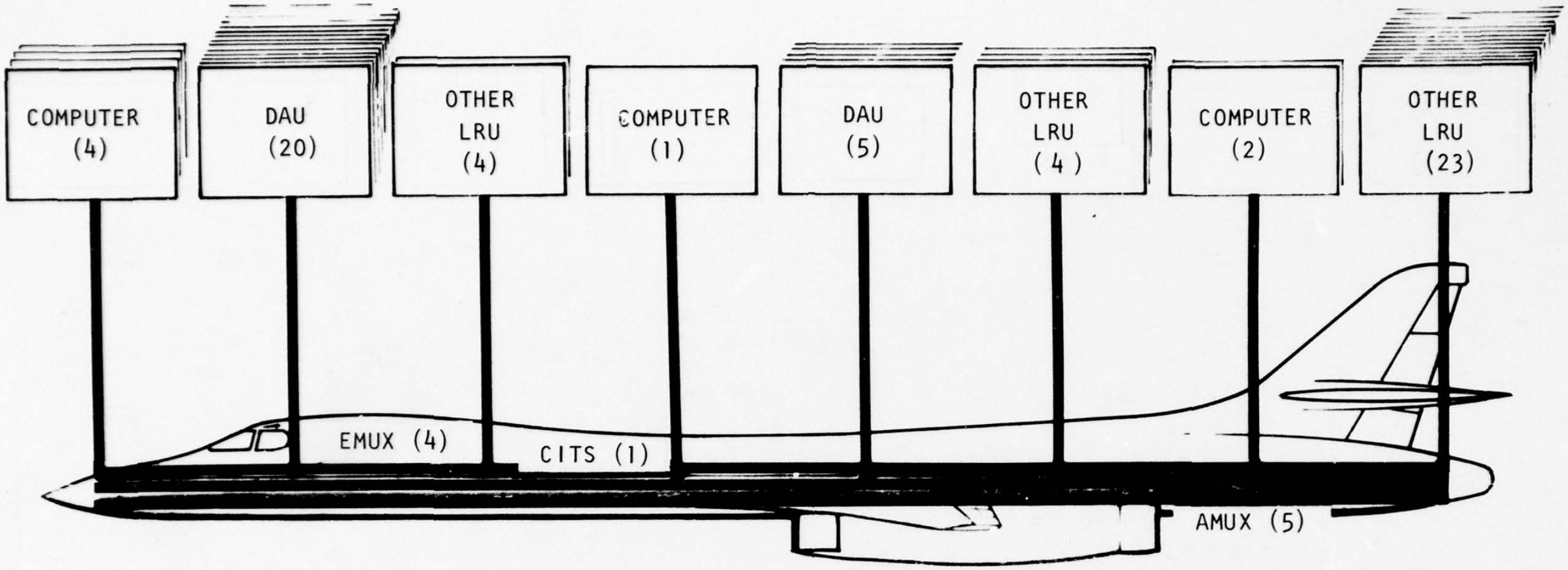
Super-MUX

The Super-MUX concept combines the data transfer capabilities of EMUX, AMUX, CITS, and 8-MUX. This is shown symbolically in Figures 22 and 23. The fiber optics Super-MUX concept would replace 36 LRU's in the wire subsystems by 27 LRU's in the Super-MUX subsystem, reducing the number of LRU's on the aircraft by nine.

Table 23 is a summary of the pertinent installation characteristics of the daisy-chain Super-MUX subsystem, showing the sources of the potential weight savings. The largest weight savings comes from the approximately 40 percent reduction in length of wire used in the subsystem over the corresponding wire configurations. Note that the corresponding number of segments is reduced by less than 20 percent. The projected weight saving is 213 pounds.

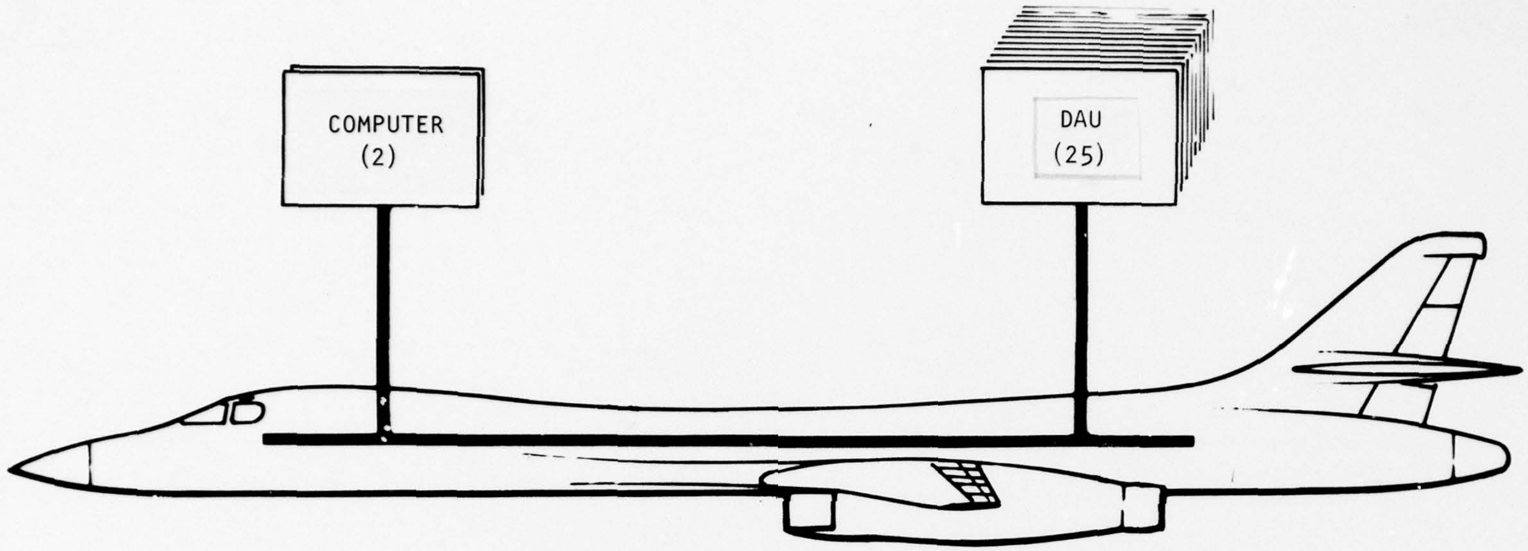
TABLE 23. B-1 SUPER-MUX DATA TRANSMISSION SYSTEM COMPARISON

Parameter	Wire	Fiber optics		Potential weight savings (lb)
		Wire	Fibers	
No. of segments	12,455	10,400	76	-
No. of terminations	24,910	20,800	152	-
Cable length (ft)	63,150	37,800	882	143
No. of bulkhead connectors	13	2	2	3
Conduit (ft)	206	94	-	11
Overbraid (ft)	353	157	-	30
No. of LRU's	36	27		26
Total (lb)				213



EACH BUS - 1 Mb/SEC

Figure 22. Present wire multiplex subsystems.



• COMBINES EMUX, AMUX, CITS, AND ADDS 8 SUBSYSTEMS

• OPERATES AT 7 MB/SEC

Figure 23. Super-MUX fiber optics concept.

DSG

Substitution of fiber optics in the DSG results in an appreciable improvement to the data transmission subsystem. Table 24 is a summary of the characteristics of the DSG in both the wire and proposed daisy chain fiber optics configurations. The segment count has been reduced by 94 percent, from 7,225 wire segments to 390 fiber optic segments. The corresponding length reduction is 91 percent, from 79,600 feet of wire to 6,800 feet of fiber optics.

The characteristics of the DSG make such savings feasible. The high data rate of the DSG requires cables of multiple wire pairs having common paths. The high bandwidth capability of fiber optics can be utilized via serial or hybrid serial/parallel multiplexing to reduce the number of data link segments drastically. It should also be pointed out that the DSG is a large data transmission system, incorporating 31 buses serving 42 LRU's and weighing 442 pounds; the very size of the system itself provides the potential for substantial weight gains.

DSG Plus Super-MUX

The Super-MUX concept, as described previously, serves 11 of the 12 B-1 systems identified as candidates for fiber optics implementation. The 12th system is the DSG, which was treated separately. Fiber optics can be accomplished on the Super-MUX and the DSG, either independently or collectively. If fiber optics were to be used on the DSG and Super-MUX collectively, the weight benefits would be additive. Thus, the combined weight saving due to fiber optics implementation on the B-1 is projected to equal 594 pounds.

TABLE 24. B-1 DSG DATA TRANSMISSION SYSTEM COMPARISON

Parameter	Wire	Fiber optics	Potential weight savings (lbs)
No. of segments	7,225	390	-
No. of terminations	14,450	780	-
Cable length (ft)	79,600	6,800	299
Connectors (No.)			
Bulkhead	22	14	3
LRU	73	55	2
Conduit (ft)	220	-	21
Overbraid (ft)	365	-	56
Total (lb)			381

TECHNOLOGICAL RISK ASSESSMENT

State-of-the-art component capabilities, subsystem operational requirements, and the B-1 environment were carefully considered in the conceptual fiber optics data transfer subsystems for the B-1. As a result, there is high confidence in the technological feasibility of these designs; the primary risks are in the system development and integration. Examples of areas where this type of risk exists are:

1. Electronics adaptations. The electronics adaptations for the DSG require data rates (approximately 20 mb/sec) that are pushing the state-of-the-art capabilities for the CMOS technology proposed.

2. Y-Couplers. No such coupler is known to currently exist, although T-couplers have been fabricated.

3. Termination loss. As previously mentioned, a 4 db termination loss for a PCFS fiber has not yet been achieved, but no known insurmountable barrier exists.

4. LED aging and temperature effects. Better methods of predicting the effect of aging and temperature on an individual LED need to be developed. Large variances within LED types occur.

5. Nuclear effects. Before a fiber optics subsystem is incorporated into a strategic aircraft, the actual components to be used would have to be subjected to exhaustive nuclear testing.

6. Cable vibration effects. Long-term vibration effects on fiber optics cables need to be evaluated, especially in the termination and cable bend areas.

In addition to the risks previously mentioned, it was pointed out that the DSG subsystem could have profitably employed multiplexing technology in 40-50 mb/sec range, but it was felt that the LSI fabrication risk and power consumption for these logic families having those rate capabilities is too high to use in a baseline concept.

Section IV

LIFE CYCLE COST ANALYSIS

GENERAL APPROACH

The objective of phase II of the FOCAP was to quantitatively establish the potential cost savings through implementation of fiber optics technology on large military aircraft. The cost evaluation consisted of (1) direct comparisons of those wire and fiber optics data transfer subsystems as defined in phase I and (2) a series of sensitivity/trade-off analyses to identify cost drivers, cost trends versus performance, and economic risks associated with fiber optics applications. This section presents the general ground rules used in the cost evaluations along with the set of equations used to make the calculations. The specific design and cost data utilized to compute the costs for both wire and fiber optic configurations are also presented, as well as the results of the direct cost comparisons. Section V of this volume addresses the sensitivity/trade-off evaluations.

In order to establish the total cost impact of fiber optics, a life cycle cost (LCC) analysis was performed. General cost categories included in life cycle cost are as follows:

1. Research, development, test, and evaluation (RDT&E)

2. Acquisition cost for total production quantity

3. Peacetime operations and support (O&S) cost for a specified time-period.

By using LCC as the basis for cost comparisons, the total cost of ownership (cradle-to-grave) is reflected. For example, if additional investment costs result in lower annual operating costs, the LCC approach will quantify whether such RDT&E costs are justified over the total span of the program.

The life cycle cost evaluations for the B-1 data transfer subsystems were accomplished as shown in Figure 24. Configuration data such as cable length, number of segments, etc, were combined with associated cost factors to determine the specific elements of LCC associated with each design. A computerized LCC model, the Data Transfer Life Cycle Cost (DTLCC) model, was used to perform these calculations. By comparing the total LCC of the candidate wire and fiber optics subsystems, the minimal cost configurations were identified.

Cost comparisons were made for the B-1 aircraft system and for a large strategic aircraft which could be resized ("rubber" aircraft) to take full

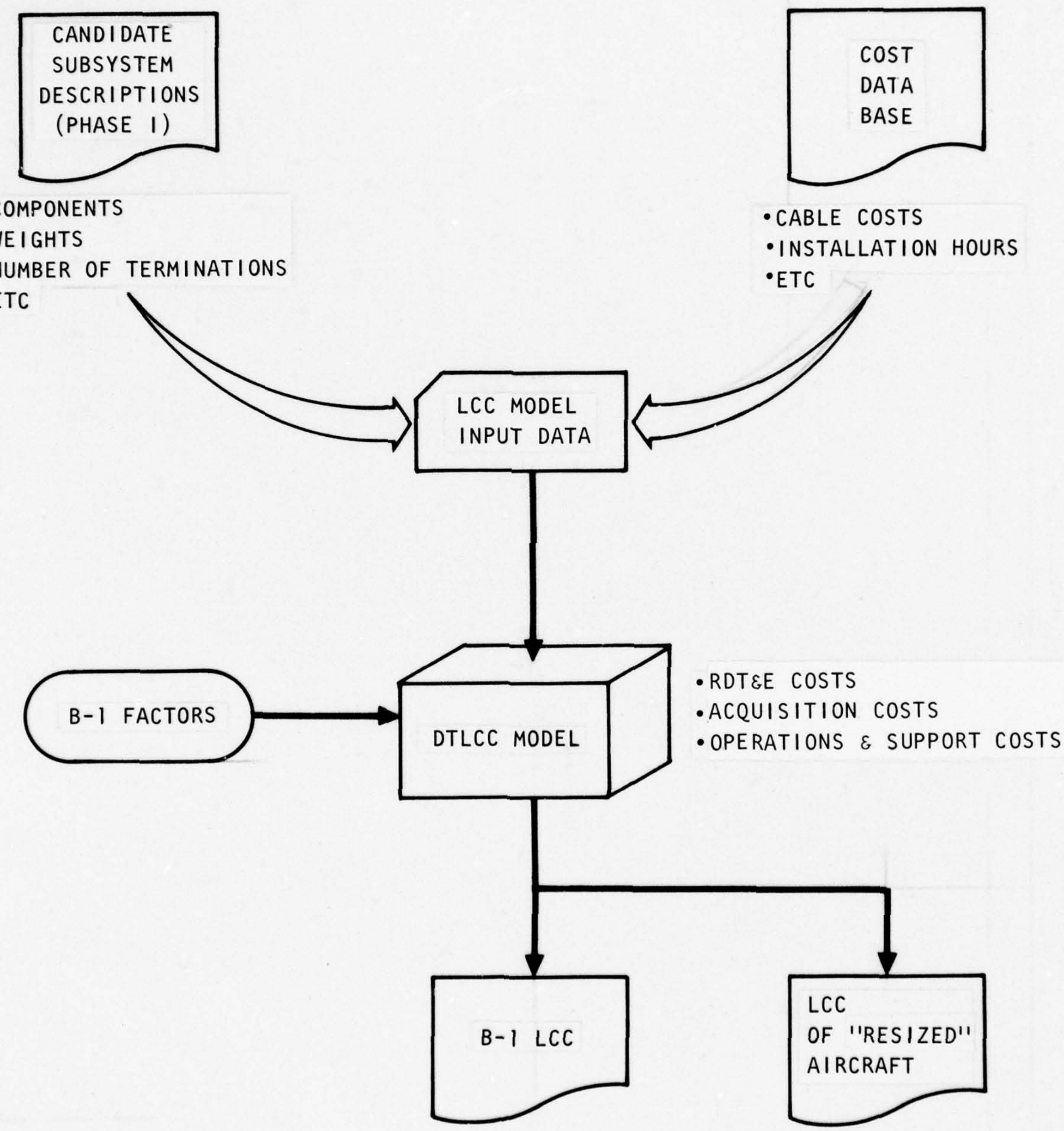


Figure 24. System flow of FOCAP LCC analysis.

advantage of any weight savings resulting from fiber optics implementation. For the B-1 cost evaluations, the weight reduction of data transfer systems was reflected as an operations and support (O&S) cost savings due to reduced fuel consumption and tanker support requirement. It was assumed that weight reductions could be incorporated during the conceptual design stage for the large-strategic-aircraft analysis, allowing for savings in the design/development, production, and overall operations and support cost of the total aircraft system.

A variety of ground rules were required in order to make the LCC evaluations. Among the study ground rules were the following:

1. All costs are for information only and are expressed in constant 1977 dollars, and do not constitute a firm commitment. No escalation and/or discounting of future costs are included in the DTLCC model.

2. RDT&E costs for the existing B-1 wire data transmission subsystems were assumed "sunk." That is, no further development cost is charged against the wire configurations.

3. Full B-1 production (240 aircraft) was assumed, and it was assumed that the fiber optics configurations could be installed during the actual production program. Therefore aircraft retrofit and modification costs need not be included in the cost evaluations. Cost factors which approximate B-1 program values (e.g., labor rates) were used.

4. Peacetime operations and support (O&S) cost are computed for a period of 10 years, and steady-state operational conditions for the current B-1 deployment plan are assumed.

METHOD OF LCC ESTIMATION

OVERVIEW OF COST CATEGORIES

The LCC analysis was designed to estimate those elements of aircraft life cycle cost which are affected by data transfer systems. Those items of aircraft LCC which do not vary if wire subsystems were replaced by fiber optic designs were treated as a constant in the cost evaluations. The specific elements of LCC considered in the analyses are listed in the following paragraphs.

RDT&E Costs

The total design/development, test, and evaluation cost was computed for each subsystem identified in phase I. It was assumed that all costs for

B-1 wire subsystems are "sunk" costs; thus, no RDT&E expenditure is associated with the wire designs. RDT&E costs for the candidate fiber optic subsystems were developed from vendor quotes (when possible) and parametric estimates.

Acquisition Costs

The following categories of data transfer system acquisition cost were treated for each subsystem (wire or fiber optic):

1. Procurement cost of each component identified in phase I
2. Direct and support manufacturing labor costs
3. LRU modification costs for fiber optic adaptation
4. Cost of added/deleted LRU's
5. Initial spares and operational support equipment (OSE)
6. Sustaining engineering and support costs

Operations and Support (O&S) Costs

The categories of O&S cost evaluated in FOCAP are as follows:

1. Corrective maintenance labor (base, shop and depot)
2. Periodic inspection
3. Corrective maintenance material (base, shop and depot)
4. Packaging, handling, and transportation
5. Recurring spares and operational support equipment (OSE)
6. Fuel and tanker support (determined by weight)

Failure rates, repair times, and hardware costs are key parameters affecting the preceding cost elements.

DELINEATION OF COST-ESTIMATING EQUATIONS

General

An accounting, or "bottoms-up," approach was used to establish the majority of subsystem cost contributions to the preceding aircraft LCC categories. The rationale for using this technique was two-fold. First, the level of detail of design characteristics specified in phase I allowed for costs to be accounted against specific components of each subsystem. Second, the lack of historical cost data on fiber optics utilization on military aircraft precluded usage of statistically derived cost estimating relationships (CER's). Only in a few cost elements were percentage factors used to estimate the subsystem contribution to aircraft LCC. In the majority of cases, the costs were determined from the specific quantities, unit prices, failure rates, etc, of the components identified as candidates for deletion/additon as wire configurations were replaced by fiber optics designs.

RDT&E Costs

As mentioned previously, RDT&E cost estimates were manually derived for each candidate fiber optic design. The general method for making these projections was to derive an estimate on one fiber optic subsystem and use extrapolation for the remaining design concepts. Vendor quotes for LRU development costs were utilized, when available. The aggregate RDT&E costs assigned to each configuration were added to the corresponding totals for acquisition and operations and support to determine LCC.

Acquisition Cost

Aircraft acquisition cost can be defined as the total cost of producing a given quantity of aircraft (also known as total flyaway cost), plus the cost of initial spares, OSE, etc, required to deploy a fleet of aircraft to meet operational requirements. It does not include the amortization of RDT&E over the prescribed production quantity, or the O&S costs. For the FOCAP study, flyaway cost translated into procurement and manufacturing (including installation) costs for the data transfer subsystem components, along with modifications to and additions/deletions of electronic LRU's as a result of fiber optics implementation. (Included in these LRU costs are the light-emitting diodes, photodetectors, etc, required for electro-optical conversion.) Both direct and indirect costs are considered in establishing flyaway costs estimates. Initial spares are determined from the price, failure rate, and repair turnaround time of the various components, and initial OSE is derived as a percentage of the calculated flyaway cost. The cost equations used to determine acquisition costs are specified in Table 25. The numerical values for the various constants used in these equations are listed in subsequent parts of this section.

TABLE 25. COST-ESTIMATING EQUATIONS FOR PREDICTING SUBSYSTEM ACQUISITION COSTS

Cost element	Estimating equation (per aircraft)
1. Cable procurement cost (wire or fiber optic)	$\$_1$ = (Cable price/ft) x (ft/subsys) x (C_1) x (C_2)
2. Procurement cost for each type of subsystem component (excluding cable)	$\$_2$ = (Unit price) x (qty/subsys) x (C_2) x (C_3)
3. Procurement cost delta of modified LRU's	$\$_3$ = Procurement cost after modification minus procurement cost before modification, where the two procurement costs are determined as in item 2.
4. Cost of manufacturing labor task(s)	$\$_4$ = (Average man-hours/task) x (No. tasks/subsys) x (L_1) (Separate calculations are made for each labor task identified; e.g., cable segment installation, conduit installation, etc.)
5. Sustaining engineering	$\$_5 = \dfrac{\text{(Total nonrecurring engrg hr/subsys)}}{\text{Number of production aircraft}} \times C_4 \times L_2$
6. Manufacturing support	$\$_6$ = (Σ direct manufacturing labor hours) x C_5 x L_1
Total flyaway cost per subsystem per aircraft	$= \sum_{i=1}^{6} \$_i$
7. Initial operational support equipment (OSE)	$\$_7$ = (Initial OSE factor) x (total flyaway)

TABLE 25. COST-ESTIMATING EQUATIONS FOR PREDICTING SUBSYSTEM ACQUISITION COSTS (CONT)

Cost element	Estimating equation (per aircraft)
8. Initial spares for wire or fiber optic cable(s)	$\$_8 = \frac{\text{(Maintenance demand rate factor)}}{\text{(Mean flight hours between segment failure)}} \times C_6$ x (base level turnaround time) x (No. segments/subsys) x (average length/segment) x (cable price/ft) x (overbuy factor)
9. Initial spares for each type of added/deleted component	$\$_9 = \frac{\text{(Maintenance demand rate factor)}}{\text{(Mean flight hours between component failure)}} \times C_6$ x (average repair turnaround time) x (qty of component/subsys) (unit price of component)
10. Initial spares for each type of modified component	$\$_{10}$ = Initial spares after modification minus initial spares before modification, where the two initial spares values are determined as in item 9.

TABLE 25. COST-ESTIMATING EQUATIONS FOR PREDICTING SUBSYSTEM ACQUISITION COSTS (CONCL)

Definition of Constants:

C_1 = Overbuy factor (ratio of total cable procured to total cable installed; ≥ 1.0).

C_2 = (Material procurement cost factor) x (general & administrative cost factor) x (fee factor).

C_3 = Material procurement cost factor (MPC), or procurement direct expense (PDE), depending upon whether the component is purchased as raw material or as a subcontracted item.

C_4 = Factor representing the ratio of sustaining engineering man-hours to total nonrecurring engineering man-hours.

C_5 = Factor representing the ratio of manufacturing support man-hours to total manufacturing direct labor man-hours.

C_6 = (Total operational aircraft, or UE aircraft) x flight hours/month/UE aircraft.

Operations and Support (O&S) Costs

The majority of O&S cost categories utilized in FOCAP were based upon the cost elements specified in Reference 9. In addition to these cost categories, specific costs associated with B-1 operations (e.g., a cost of $118 per pound per aircraft due to fuel and tanker support) were included in the cost evaluations. The B-1 fuel cost factor was derived through an evaluation of aircraft fuel consumption as a function of aircraft weight. 27 flying hours per month per aircraft, and a fuel burn rate of 100 lbs of fuel per 1000 lbs of weight were assumed. The B-1 fuel cost factor equates to $40 per pound per aircraft. The tanker cost factor is also based on the change in B-1 fuel consumption with weight, and consists of both operations costs due to changes in tanker flight hours as well as changes in the total tanker fleet size, including tankers on alert. An equal range capability for the B-1 alert force is maintained. The tanker costs equate to $78 per pound per aircraft. The annual O&S cost equations are presented in Table 26. These equations were multiplied by 10 to determine the total cost over 10 years of steady-state operations for the B-1 fleet.

"RUBBER"-AIRCRAFT LCC ANALYSIS

Approach

The rubber-aircraft approach involved the extrapolation of B-1 results to a large strategic aircraft (LSA). Weight savings due to fiber optics have a cascading effect on the LSA analysis, with the physical size and propulsion requirements of the aircraft being adjusted as a result of electrical system weight changes. Since these system-level parameters influence total aircraft design/development, acquisition, and fleet operations and support costs, the cost benefit of fiber optics is greater for the rubber aircraft.

This study utilized vehicle synthesis and parametric LCC estimating models which were developed for conceptual design studies. These computer programs are based on the size, weight, material mix, and performance characteristics of the aircraft in question. The costs generated in this exercise were system-level LCC, and were combined with discrete cost deltas from the B-1 evaluations to establish the total potential cost advantage of fiber optics for a rubber aircraft. It must be emphasized, however, that this cost savings could only be realized if fiber optics were incorporated at the conceptual design stage of a large-strategic-aircraft development program.

In this analysis, the cascading effect of avionic/electrical system weight reductions is emphasized by allowing the aircraft to "shrink" as the dead weight is decreased. The objective was to establish the LCC payoff per pound of data transfer system weight removed. This dollar-per-pound value is

then applied to the discrete weight deltas identified in phase I to demonstrate the LCC savings which may be anticipated if fiber optics technology were incorporated at the conceptual design stage for a large strategic aircraft.

To perform such a theoretical exercise requires the following sequence of steps:

1. A baseline aircraft configuration must be defined in sufficient detail to allow for realistic cost assessment of changes in airframe and propulsion system weights and geometry.

2. A set of ground rules constraining the "rubberization" of the configuration must be established. The choice of such ground rules can have a major effect on the magnitude of weight cascading.

3. Parametric analyses must be performed to compute the changes in weight, geometry, and performance as a function of reductions in data transfer system weight. Concurrent life cycle cost calculations are made on the rubberized aircraft to establish the total cost impact of fiber optic weight savings.

4. These cost results are combined with the discrete cost deltas from the B-1 LCC evaluations to obtain the theoretical potential LCC savings of fiber optics in large strategic aircraft.

Description of Analytical Tools

The rubber-aircraft dollars-per-pound evaluation was accomplished using computer programs to perform both vehicle synthesis and LCC calculations. The Vehicle Sizing and Performance Evaluation Program (VS/PEP) was used to assess the cascading of weight savings to the total aircraft configuration. This model mathematically evaluates conceptual aircraft designs with respect to prescribed mission profiles. It is an analytical tool for "resizing" base-point configurations to reflect the range and payload requirements for a mission. The model serves as a means for performing trade studies on design parameters (e.g., wingloading/dead weight) for configurations of interest.

Parametric cost estimating models were utilized to translate the aircraft configuration changes due to weight savings into life cycle cost savings. The first computer program, the RDT&E cost model, was used to estimate total research and development costs. It is characterized by its work breakdown structure (WBS) cost format, and its sensitivity to a wide range of cost-influencing factors. The Production Cost Model (PCM) was used to calculate aircraft production costs. This cost model also estimates cost in a standardized WBS format, and is sensitive to such design variables as weight, airframe material mix, performance critiera, and production rate. Operations and support (O&S) costs were estimated by the FCOST life cycle

TABLE 26. COST-ESTIMATING EQUATIONS FOR ANNUAL SUBSYSTEM O&S COSTS

Cost element	Estimating equation
1. Cable maintenance	$\$_1 = C_1$ x (MDR factor/MTBF) x (number of segments) x (mtl \$/repair + [man-hours/repair] [C_2])
2. Added/deleted LRU maintenance	$\$_2 = C_1$ x (MDR factor/MTBF) x (number of LRU's) x ([man-hours/dirr] [C_2] + [man-hours/rep] [C_2] [fract base] + [man-hours/rep] [C_3] [fract depot] + [mtl \$/repair] [fract base] + [mtl \$/repair] [fract depot] + [unit weight] [C_4] + [unit weight] [C_5] [fract depot])
3. Modified LRU maintenance	$\$_3$ = LRU maintenance cost after modification minus LRU maintenance cost before modification, where the two maintenance costs are determined as in item 2.
4. Recurring spares for added/deleted LRU's	$\$_4 = C_1$ x (MDR factor/MTBF) x (number of LRU's) x (unit price) x (condemnation rate)
5. Recurring spares for modified LRU's	$\$_5$ = Recurring spares after modification minus recurring spares before modification, where the two recurring spares costs are determined as in item 4.

TABLE 26. COST-ESTIMATING EQUATIONS FOR ANNUAL SUBSYSTEM O&S COSTS (CONCL)

Cost element	Estimating equation
6. Scheduled maintenance (i.e., inspections)	$\$_6$ = (scheduled maintenance actions/year) x C_6 x ([man-hours/action] [C_2] + mtl \$/action)
7. Recurring OSE	$\$_7$ = (initial OSE) x C_7
8. Fuel & tanker support	$\$_8$ = (subsystem weight) x (C_8) x C_6

Definition of Constants

C_1 = (Flight hours/year/UE) (number of UE A/C)

C_2 = Base labor rate

C_3 = Depot labor rate

C_4 = \$/lb for LRU packaging and handling

C_5 = (Standard ratio of shipped weight to packaged weight) x (\$/lb shipping for LRU's)

C_6 = Number of UE A/C

C_7 = Recurring OSE factor

C_8 = Fuel and tanker support \$/lb

cost model, using statistically derived equations to predict such cost factors as maintenance man-hours per flight-hour (MMH/FH) and replenishment spares. Documentation on the CER's for RDT&E, PCM, and FCOST models is contained in References 10, 11, and 12, respectively.

Functional relationships for typical CER's in the three cost models are shown below.

RDT&E

Fuselage Engineering Design Cost	=	f (Dynamic pressure, wetted area, aircraft length, gross weight, and labor rate)

PCM

Fuselage Manufacturing Labor Cost	=	f (Fuselage weight, material and construction type(s), and labor rate)

FCOST

Recurring Spares	=	f (Mach number, gross weight, aircraft type)

Results of "Rubber"-Aircraft analysis

Table 27 represents a weight summary sheet for a large strategic aircraft showing the relationship between takeoff gross weight and the reduction of avionic/electrical system weight as derived by VS/PEP. This weight summary assumes a constant thrust-to-weight ratio and a constant wingloading (i.e., ratio of takeoff gross weight to wing area). Thus, the aircraft maintains a constant flight envelope performance. Figure 25 depicts the variation in aircraft growth factor as derived from Table 27, where growth factor is defined as the change in takeoff gross weight divided by the change in avionics weight.

The LCC savings for production aircraft per pound of avionics/electrical system weight reduction was computed to be $1,127 per pound (1977 dollars). This aggregate dollars-per-pound value represents the sum of dollars-per-pound factors for the various categories which comprise life cycle cost. Table 28 presents a breakdown of the $1,127-per-pound factor. These values were computed by dividing the change in cost between two configurations of different avionic/electrical system weights (as calculated in the three cost models) by the corresponding weight differential. As the table indicates, flyaway cost delta per pound of avionic/electrical system weight reduction accounts for about 40 percent of the total LCC saving.

TABLE 27. WEIGHT SUMMARY*

Aircraft Weight Category	Avionics Weight Change			
	Baseline	-300 lb	-600 lb	-1,000 lb
Structure	(98,182)	(97,753)	(97,335)	(96,788)
Wing	39,783	39,610	39,440	39,218
Tail - horizontal	5,224	5,201	5,180	5,150
- vertical	1,773	1,765	1,758	1,748
Body	26,358	26,243	26,130	25,984
Alighting gear - main	12,490	12,436	12,383	12,313
- auxiliary	1,802	1,794	1,786	1,776
Engine section or nacelle	6,144	6,117	6,051	6,057
Air induction system	4,312	4,293	4,275	4,251
SMCF	99	99	98	98
Emp fairing	196	195	194	193
Propulsion	(20,632)	(20,539)	(20,448)	(20,330)
Engine (as installed)	17,212	17,134	17,058	16,960
Accessory gearboxes & drives	715	712	709	705
Exhaust system				
Cooling & drain provisions	20	20	20	20
Engine controls				
Starting system	180	179	178	177
Fuel system	2,505	2,494	2,483	2,468
Fan (as installed)				
Hot-gas duct system				
Equipment	(26,203)	(25,878)	(25,554)	(25,138)
Flight controls	3,563	3,552	3,545	3,536
Auxiliary powerplant	440	440	440	440
Instruments	815	815	815	815
Hydraulic & pneumatic	1,795	1,790	1,784	1,781
Electrical	3,085	3,076	3,065	3,061
Avionics	7,223	6,923	6,623	6,223
Armament	1,945	1,945	1,945	1,945
Furnishings and equipment	3,017	3,017	3,017	3,017
Air conditioning	4,180	4,180	4,180	4,180
Anti-icing				
Photographic	45	45	45	45
Load & handling				
Auxiliary gear	95	95	95	95

TABLE 27. WEIGHT SUMMARY* (CONCL)

Aircraft Weight Category	Avionics Weight Change			
	Baseline	-300 lb	-600 lb	-1,000 lb
Total weight empty	145,017	144,170	143,337	142,256
Crew	860	860	860	860
Fuel - unusable	705	701	697	693
Fuel - usable	159,118	158,281	157,455	156,383
Oil - engine	380	378	376	373
Passengers/cargo				
Armament - Launchers	3,240	3,240	3,240	3,240
- missiles	50,000	50,000	50,000	50,000
Equipment	180	180	180	180
LN_2	500	500	500	500
Total useful load	214,983	214,140	213,308	212,229
Takeoff gross weight	360,000	358,310	356,645	354,485

*Constant thrust-to-weight (T/W) ratio and constant wingloading assumed.

TABLE 28. BREAKDOWN OF "RUBBER"-AIRCRAFT DOLLARS PER POUND (1977 DOLLARS)

	Dollar savings per pound of avionic/electrical system weight reduction (per aircraft)
RDT&E	166
Airframe	(142)
Propulsion	(24)
Acquisition	543
Flyaway	(426)
Spares, training, etc	(117)
Operations & Support	418
Fuel	(31)
Tanker support	(194)
Maintenance, spares, etc	(193)
Total	1,127

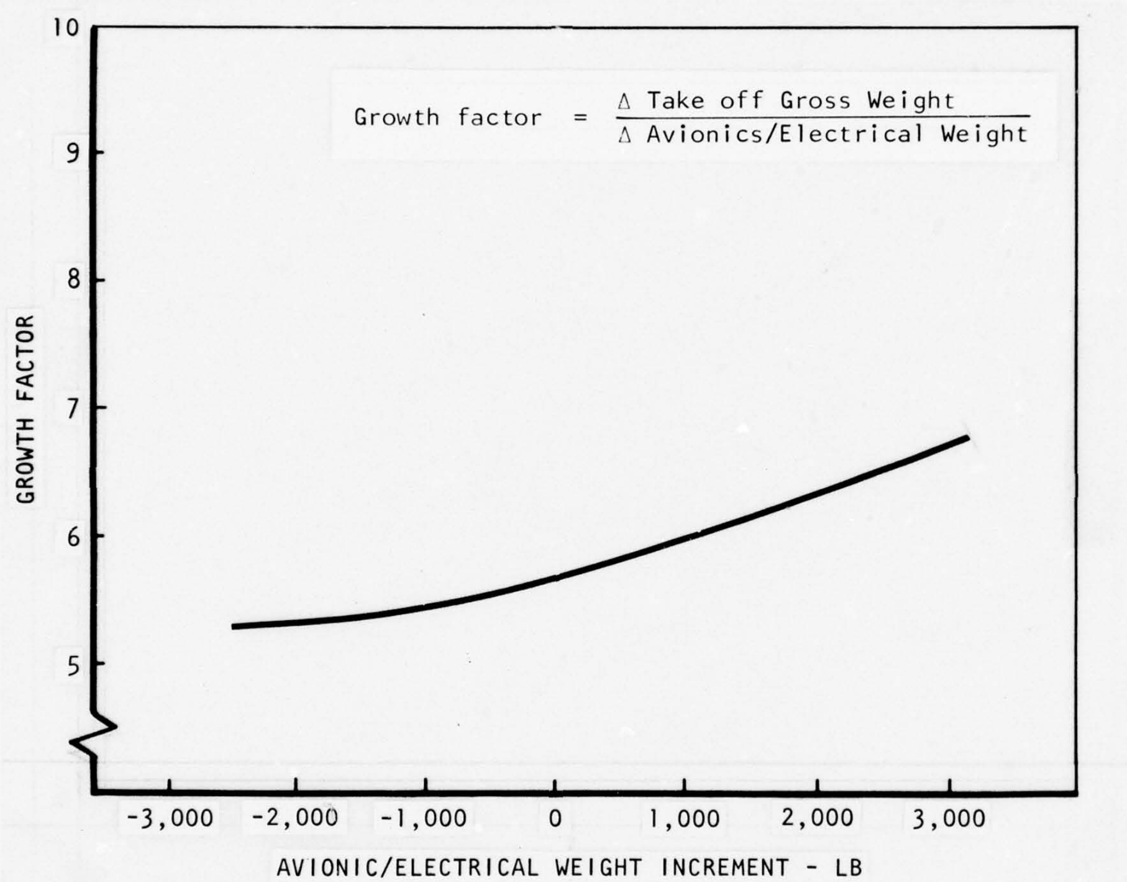


Figure 25. Variation in growth factor due to avionic/electrical system weight change.

DESCRIPTION OF DATA TRANSFER LIFE CYCLE COST MODEL

In order to expedite the FOCAP cost evaluations, a computerized life cycle cost model was utilized. This program, the Data Transfer Life Cycle Cost (DTLCC) model, evaluates the various categories of LCC as discussed previously, thus allowing for cost evaluations as a function of subsystem design characteristics and their associated cost factors. Due to the level of detail of inputs, the model is also useful for sensitivity analysis and major cost drivers identification. The model calculates the LCC of a fixed-size aircraft and, as an option, the change in LCC of a large strategic aircraft that is allowed to "shrink" as the weight of the data transfer subsystem is reduced (rubber aircraft).

The first step in calculating life cycle costs is to define each of the candidate data transfer subsystems in terms of design parameters. This includes the length and segment count of each type of wire or cable; the number of line replaceable unit (LRU's) being modified, added, or deleted; and the number of miscellaneous components in the candidate subsystem. Manufacturing, procurement, reliability, and maintainability factors must then be collected for each item of design information. All of these factors then are used as inputs to the model, and the program calculates the life cycle cost contribution of each subsystem. It then adds the cost contributions of all candidate subsystems and combines these with the costs unaffected by the data transfer subsystems tc determine the total aircraft life cycle cost. Figure 26 provides an overview of the DTLCC model operation.

The DTLCC model output displays the life cycle cost breakdown in terms of RDT&E, acquisition, and O&S for 10 years of steady-state operations. A sample of this output is shown in Figure 27. In addition, the model has several other pages of output of increasing detail, in order to provide a specific breakdown of life cycle cost categories.

Further details on the DTLCC model can be obtained in Reference 13.

DATA COLLECTION

The set of cost-estimating equations discussed previously utilize a variety of design and cost data as input parameters. A major task of FOCAP was to assemble this information for use on the LCC evaluations and the sensitivity/tradeoff analyses. Configuration data for the various subsystem designs were extracted from phase I results, and the remaining information was obtained from Government publications, vendor quotes, and parametric estimates. Representative values were assigned to general cost factors such as labor rates and overhead expense percentage. The following paragraphs

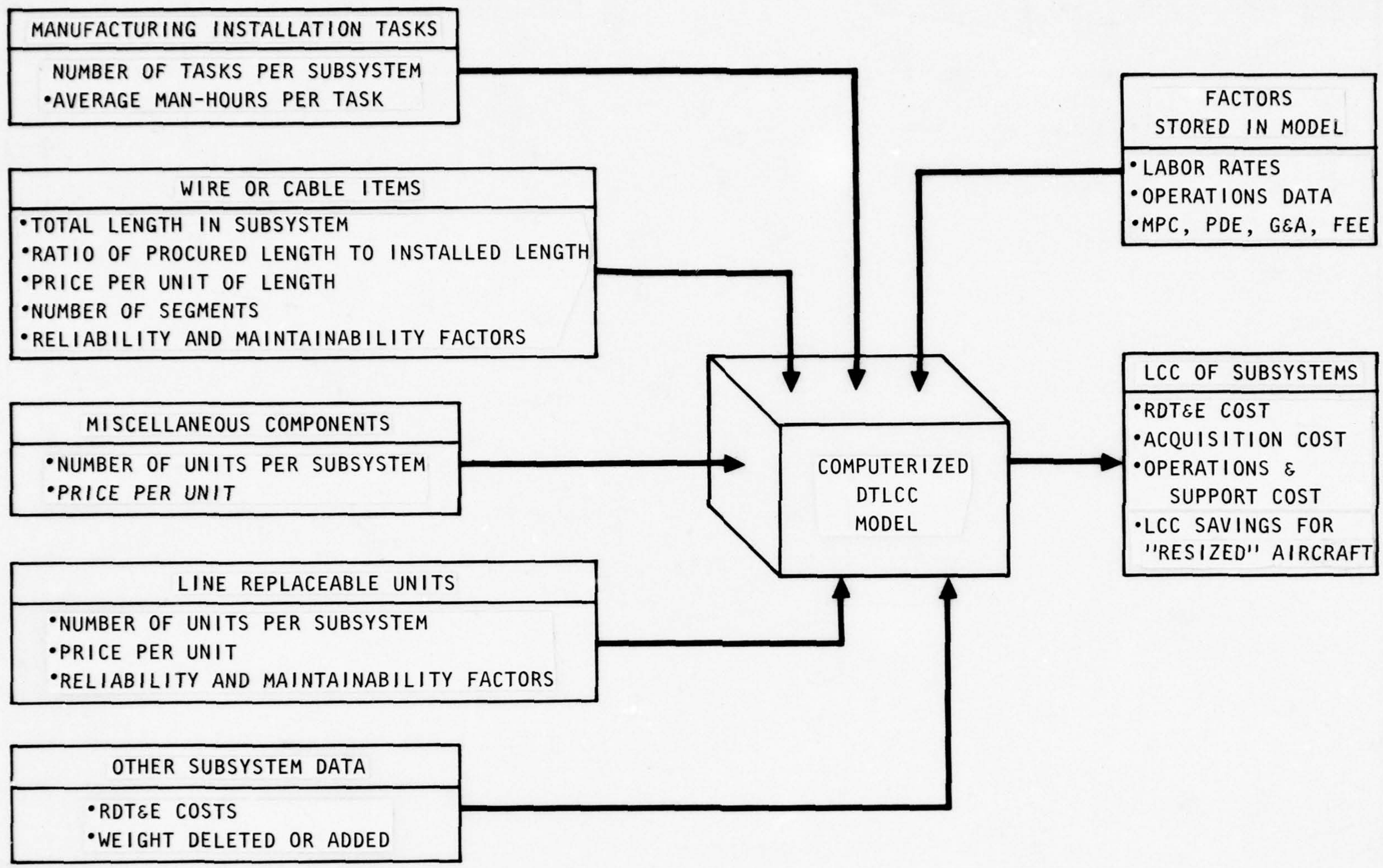


Figure 26. Overview of data transfer life cycle cost model.

NEW DESIGN DAISY CHAIN ADDITIONS-- SUPERMUX,DSG

DATA TRANSFER SYSTEMS LIFE CYCLE COST (LCC)
FOR TEN YEARS OF STEADY STATE OPERATIONS
IN FY 1977 MILLION DOLLARS

SUBSYSTEM	NAME	TYPE	RDT&E	ACQ'N	OPERATIONS	LCC
1	SUPERMUX	F.C.	28.800	836.575	345.030	1210.405
2	DSG	F.O.	5.070	9.394	2.408	16.872
DATA TRANSFER SYSTEMS			33.870	845.969	347.438	1227.277
FIXED COSTS			4320.250	13362.927	6877.437	24560.614
TOTAL COSTS			4354.120	14208.896	7224.875	25787.891

Figure 27. Sample output from data transfer life cycle cost (DTLCC) model.

document the input data used in the study. All costs are expressed in 1977 dollars and are based on procurement quantities consistent with the full B-1 production plan (240 aircraft).

Subsystem Description Data

The following configuration data items were required for each wire or fiber optic subsystem:

1. Length of cable (by type)

2. Number of cable segments

3. Length of conduit

4. Length of overbraid

5. Number of bulkhead and end connectors

6. Number of couplers of each type

7. Quantity and weight of modified, added, or deleted LRU's

8. Subsystem weight

Section III of this report provides the numerical values for these data by subsystem. Note that for the wire configurations, the quantities and weights represent only those hardware items which can be deleted by conversion to fiber optic data transmission. The corresponding information on the fiber optic designs represents those components which replace the deleted wire components.

RDT&E Costs

The RDT&E costs for each data transmission subsystem included the following tasks: (1) design of optoelectronic interfaces to present LRU's, (2) modification of LRU's to accept these interfaces, (3) subsystem installation, including routing, (4) testing, (5) and a host of smaller tasks necessary to integrate a subsystem into a complex weapon system like the B-1.

Present B-1 Systems

The method of estimating the RDT&E cost varied, depending upon whether the subsystem is presently on the B-1 (DSG, EMUX, AMUX, or CITS) or is a

completely new subsystem concept (8-MUX or Super-MUX). For the subsystems already on the B-1, it was assumed that the interface electronics for a subsystem would be designed by a single supplier and that these electronics would be integrated into each LRU by the LRU manufacturer. Rockwell would install the LRU's and complementary fiber optics links aboard the B-1 and test the integrated subsystem. The cost of development of the interface electronics was derived from specific industry queries (e.g., DSG), experience with similar types of interface modules on the B-1 (e.g., AMUX multiplex interface module), and comparison of electronic interface complexity. Typically, it is estimated that the development of the interface electronics will cost $600,000 to $900,000, depending on the subsystem. This cost is only slightly dependent upon whether the electronics are designed for retrofit or new design application.

Inquiries made to the manufacturers of LRU's revealed a wide range of costs projected to modify an existing LRU, depending on the amount of space available in the present LRU, the uniqueness of the LRU, etc. Costs ranged from $50,000 to $130,000 for a retrofit, and from $50,000 to $170,000 for a modification to an LRU incorporating a new design. The total RDT&E costs associated with the modification of the LRU, including development of the interface electronics and incorporation of the electronics in the subsystems LRU's, are shown in Table 29.

In order to estimate the effort required to install modified LRU's and the fiber optics aboard the B-1 and to test the integrated subsystems, a detailed analysis was made of the DSG, and the results were extrapolated to the other subsystems according to their relative complexities. Over 20 separate engineering functions were identified as having tasks to perform to put a fiber optics DSG aboard the B-1. The task descriptions and man-hours are available in Reference 14. For the DSG daisy chain configuration, a total of 48,900 man-hours are required for the retrofit concept, and 47,600 hours for the new design concept. These engineering man-hours and those extrapolated for the other present subsystems are shown in Table 29.

Also shown in Table 29 are the total RDT&E costs for these subsystems. The total costs are the sum of the LRU modification costs and the B-1 man-hour costs.

New Fiber Optics Subsystems

The 8-MUX and Super-MUX subsystems are completely new concepts. They would require complete subsystem design, including the computer design and software development. The RDT&E costs associated with these subsystems are shown in Table 30. The subsystem hardware and software costs were derived by comparing these subsystems with the same type of subsystems already on the

TABLE 29. RDT&E COSTS; PRESENT B-1 SUBSYSTEMS (1977 DOLLARS)

Subsystem	LRU modification ($1,000's)	B-1 man-hours (1,000's)	Total cost ($1,000's)
DSG			
Star coupler			
Retrofit	2,900	65	5,000
New design	3,300	64	5,400
Daisy chain			
Retrofit	2,900	49	4,600
New design	3,300	48	5,100
EMUX			
Star coupler			
Retrofit	900	31	1,800
New design	1,200	28	2,000
Daisy chain			
Retrofit	900	26	1,600
New design	1,200	25	2,000
AMUX			
Star coupler			
Retrofit	2,800	45	4,500
New design	2,900	35	4,300
Daisy chain			
Retrofit	2,800	38	4,300
New design	2,900	32	4,300
CITS			
Retrofit	1,500	15	2,200
New design	1,700	12	2,400

TABLE 30. RDT&E COSTS - NEW FIBER OPTICS SUBSYSTEMS (1977 DOLLARS)

Item	8-MUX	Super-MUX Star Coupler	Super-MUX Daisy Chain
Hardware development[1]			
Computer	$2,000K	$10,000K	$10,000K
Data acquisition units	$1,000K	$ 1,000K	$ 1,000K
Software development[2]			
Man-hours	Included in engrg hr	417.6K	417.6K
Data processing	Small	$ 718K	$ 718K
Engineering man-hours[2]	134.5K	230.6K	228.3K
Total costs	$6,690K	$28,860K	$28,800K

[1] Vendor estimates

[2] Rockwell estimates

B-1 (CITS, EMUX, and AMUX), and extrapolating those costs, taking into account advances in computer technology since the subsystems were designed. Similarly, the engineering man-hours estimates were based upon B-1 experience with EMUX, AMUX, and CITS.

Unit Cost for Wire Subsystem Components

Phase I identified a set of four component types (excluding LRU's) which are associated with B-1 wire data transfer subsystems. Estimates of the average unit cost of these components for the B-1 production program follow. The values do not include material procurement cost (MPC), general and administrative cost (G&A), or fee.

1. Wire (per foot)

22-gage (average)	$ 0.38 per foot
24-gage	$ 0.33 per foot

2. Bulkhead connectors (each)

Receptacle		$ 55.00
Plug		90.00
Backshell		12.00
	Total	$157.00

3. Overbraid (per foot) $ 1.25

4. Conduit (per foot) $ 8.60

5. End connectors (each) $102.00

Unit Cost for Fiber Optic Subsystem Components

Phase I activities included the selection of fiber optic subsystem components which have physical properties consistent with B-1 weapon system specifications. A variety of fiber optic component suppliers were contacted to ascertain cost estimates for these items. The paragraphs that follow summarize the cost data collected. The costs do not include MPC, G&A, or fee.

Fiber Cables

A unit cost estimated for seven- and 19-fiber plastic-clad, fused silica core (PCFS) fiber optic cable was obtained. Rockwell requested that the cable

have a 35-pound tensile strength and that the cable be tested to the B-1 environmental conditions. The unit costs for the seven- and 19-fiber PCFS cable as obtained from a vendor are shown in Figure 28. In addition, the development cost is estimated to be approximately $51,000 for the seven-fiber cable, and $60,000 for the 19-fiber cable. The 19-fiber cable was used in the FOCAP study, and a value of $2 per foot was established from these data for input to the DTLCC model. Sensitivity analyses were made over the range of costs displayed to determine the impact of fiber cable prices on LCC.

Optical Couplers

The following price estimates for nine-port star couplers were received from a vendor:

Quantity	Unit Price
100	$408
1,000	245
10,000	150

The value selected for the cost evaluations was $200 per star coupler. A similar cost assessment for Y-couplers resulted in an average unit cost of $65.

Connectors

Cost estimates for two matrix parts of a fiber optic cable bulkhead connector for six-, 12-, and 16-pin connectors as obtained from a vendor are:

Quantity (units)	6 Pins	12 Pins	16 Pins
1,000	$41.00	$62.00	$76.00
2,500	40.00	60.76	74.48
5,000	39.00	59.94	73.00
10,000	38.59	58.35	71.53
25,000	37.82	57.78	70.10

The value chosen for bulkhead connectors was $73 each (16 pins). End connectors at LRU's were assumed to be $36.50 each (16 pins).

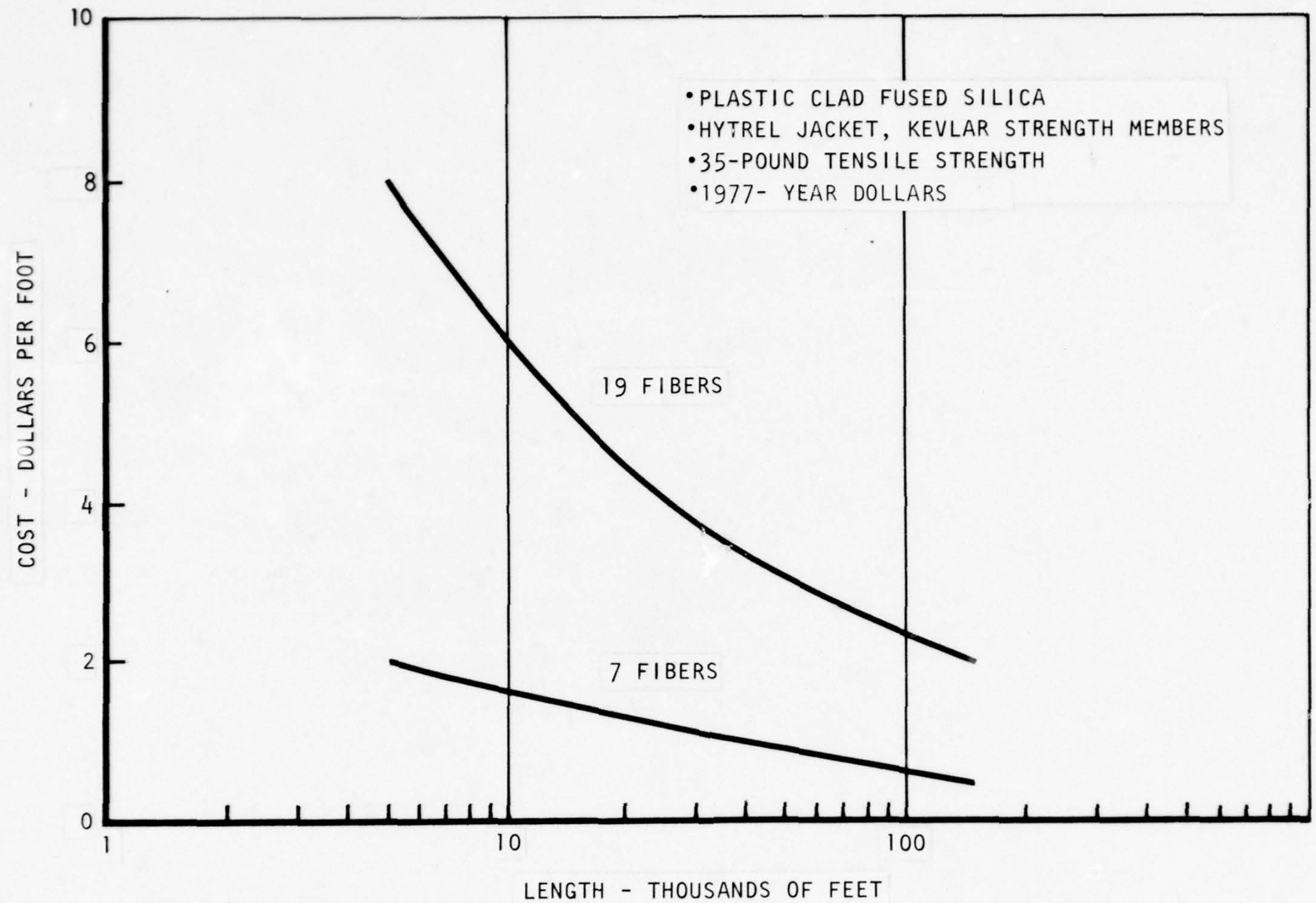


Figure 28. Fiber optic cable cost. (Vendor estimate)

Direct Manufacturing Hours

Direct manufacturing hours were developed for those tasks directly associated with component preparation and installation for wire and fiber optic subsystems. For wire subsystems, the components considered were cables (including overbraid), conduits, and bulkhead connectors. For fiber optics subsystems, the components considered were cable, bulkhead connectors, LRU installation and checkout, and optical couplers. The approach was to establish man-hour standards for the first production aircraft (i.e., T_1 values) and to extrapolate these values on appropriate learning curves to compute average man-hours per task for the full B-1 production program.

Cable Preparation and Installation

The manufacturing effort associated with cable preparation and installation on an aircraft is dependent upon the number of cable segments and is always computed as the product of the number of segments and the man-hours per segment. Historical data on the B-1 aircraft were used to establish the man-hour standard for wire segment installation. Engineering estimates were made to determine the corresponding standard hours for the 19-fiber bundle fiber optics cable. The preparation method for the fiber bundles is assumed to be as follows:

1. Cut fiber optic cable to required length, allowing about 6 inches of slack for termination.
2. Strip away 2-1/2 to 3 inches of cable jacket, exposing fiber and Kevlar strength members.
3. Place end of cable in a holding fixture (in a vertical position), and spray fiber with Freon to remove any oil from fibers.
4. After Freon has dried, spray fibers with Freon a second time, and allow to dry.
5. Apply epoxy to exposed fibers.
6. Install connector crimp sleeve and ferrule over fibers.
7. Apply epoxy to Kevlar strength members, and slide connector crimp sleeve into position on cable jacket, over strength members.
8. Trim away excess Kevlar strength members.
9. Crimp sleeve using a standard crimping tool.

10. Place cable 6 to 9 inches from 250° F infrared lamp, and cure epoxy for approximately 55 minutes, or 5 to 10 minutes using a heat gun.

11. Remove excess fibers using a 400-grit wheel, and polish fibers using 320-, 12-, and 3-micron lapping wheels.

12. After completion of polishing, visually inspect end of terminated cable (fiber bundle) under a microscope.

Installation of the fiber optics cables includes the following tasks:

1. Route prepared cables through aircraft.

2. Clamp cables at required intervals.

3. Insert ends of prepared cables (ferrules) into connector shells.

4. Fasten connectors to LRU's

The results of the man-hours estimates analysis for wire and fiber optic cable segment preparation and installation are shown in Table 31. An average learning curve of 73 percent as projected for the B-1 production on basis of previous experience was applied to these standard man-hours, resulting in an average 0.645 man-hour for wire and 0.85 man-hour for fiber optic cable segment preparation and installation.

Other Component Preparation and Installation

Preparation and installation man-hours estimates were developed for other wire and fiber optics components, and are presented in Table 32. Overbraid preparation and installation is included in the wire segment preparation and installation.

TABLE 31. WIRE AND FIBER OPTIC SEGMENT PREPARATION AND INSTALLATION

	Man-hours per segment (first aircraft)	
	Wire	Fiber optic
Preparation	2.3	1.4
Installation	1.8	4.0
Q&RA testing (after installation)	0.3	0.4
Total	4.4	5.8

TABLE 32. PREPARATION AND INSTALLATION MAN-HOURS

Component	First aircraft	Fleet average[a]
Bulkhead connectors (each)	6	0.88
LRU (each)	6	.97
Conduit (per foot)	1	.15
Data link terminators (each)	1	.15
Star couplers (each)	1	.15
Y-couplers (each)	1	.15

[a]Assumes 73-percent learning curve for 240 production aircraft.

Line Replaceable Unit (LRU) Costs

The B-1 wire subsystems descriptions prepared in phase I identified the electronic LRU's which are associated with data transfer in each subsystem. Representative average unit procurement costs were obtained for each type of LRU, and then engineering estimates were made on the cost delta per LRU to accommodate fiber optic data transmission. Both retrofit and new design configurations were considered. In those fiber optic configurations requiring new LRU's, engineering estimates were made (based upon analogy to existing LRU's) to establish their unit procurement costs. All of these data were utilized in the LCC comparisons.

Baseline LRU Costs

Table 33 displays the cost for LRU's which are used in the FOCAP study.

LRU Modification Costs

In the new design subsystems concepts for EMUX, AMUX, CITS, and the DSG, it is assumed that the recurring LRU costs and failure rates for fiber optics and the present recurring LRU costs for wire subsystems will be equal. The new design interface adaptations for EMUX, AMUX, and CITS (appendixes D and E) would be of similar complexity, size, and weight to the components which they replace.

The new design DSG fiber optics interface adaptations would be of similar complexity, size and weight as the units they replace. Even though

TABLE 33. BASELINE COST FOR LRU'S

(Average unit cost - 1977 dollars, excluding PDE, G&A, or fee.)

Subsystem	LRU type	Quantity/ subsystem	Unit cost ($)	Total Cost M$
DSG	PACU I/O	2	104,000	
	Jammer	2	48,000	
	Encoder	6	59,000	
	Driver	6	34,000	
	RF source	7	33,000	
	Transmitter	10	23,000	
	Antenna	9	13,000	
				1.44
EMUX	Box - discrete	2	51,300	
	Box - discrete digital	6	142,800	
	Box - discrete	10	80,400	
	Box - control	4	131,700	
	Box - discrete	2	80,900	
	Box - CITS interface	2	33,500	
				2.52
AMUX	ACU*	17	195,000	
	FISC*	10	25,000	
				3.57
CITS	DAU	5	42,400	
	Printer	1	42,400	
	Recorder	1	50,800	
	Control & display	1	58,600	
	Computer	1	69,800	
	CDR/CPI	1	108,300	
				0.54
8-MUX	DAU	9	51,000	
	Controller	2	102,000	
				0.66
Super-MUX	DAU	25	51,000	
	Computer	2	510,000	
				2.29

*Representative for cost purposes.

a fiber optics interface in the DSG would require fewer drivers/receivers compared to the present wire interfaces, the component count would be comparable due to the following:

1. The DSG presently employs a parallel-type of interface to the wire data buses.

2. A fiber optics interface will utilize fewer channels transmitting serial or hybrid parallel/serial data.

3. Parallel-to-serial and serial-to-parallel data conversion would require some circuitry.

4. In addition, the multiplexing task would also require circuits for timing and control of the converters (i.e., clocks, gating, and timing generators).

In this case, a large number of relatively simple circuits would be replaced by a smaller number of more complex circuits. As a result, it is assumed that the size, weight, reliability, and cost of LRU's employing wire and fiber optics interfaces would be approximately the same. Table 34 summarizes the costs associated with modification and addition of LRU's to accomplish fiber optics implementation on each subsystem.

Table 34 also displays the average unit cost delta per LRU for the retrofit design concepts. These costs include the labor as well as hardware costs of the modifications. The breakdown of those cost elements was not available. These costs were derived through estimates based upon vendor quotes on LRU modification cost plus those costs associated with the hardware required for the electronic adaptations. Technical descriptions of these adaptation units are contained in Section III of this report for the DSG, and Appendix C for EMUX, AMUX, and CITS.

Table 34. RECURRING COST DELTAS FOR LRU MODIFICATIONS (FY 1977 dollars, does not include PDE, G&A, or fee.)

Subsystem	Unit Δ cost (new design)	Unit Δ cost (retrofit)
DSG	0	+5,100
AMUX	0	+3,800
EMUX	0	+3,800
CITS	0	+3,100

Reliability/Maintainability

Modified LRU's

As noted in the paragraph on LRU costs, the new design LRU's for EMUX, AMUX, CITS, and DSG are of similar complexity as the unit which they replace. Therefore, it is assumed that new design modification to LRU's would result in no net change in each LRU failure rate. In the retrofit concept, an interface adaptation unit ("card") is inserted into each modified LRU. Based on complexity estimates and analogy with existing electronic units, mean-time-between failure (MTBF) estimates were derived for each retrofit interface unit, and are presented in Table 35. Those MTBF values are for single interface adaptation unit and do not represent failure rates for entire subsystems.

TABLE 35. RELIABILITY OF RETROFIT INTERFACE UNITS

Subsystem	MTBF (hours)
EMUX	30,000
AMUX	30,000
CITS	60,000
DSG	4,600

The reciprocal of the MTBF (i.e., failure rate) of each interface unit was added to the baseline failure rate of each corresponding LRU to determine the net failure rate of each retrofit LRU. For both new design and retrofit LRU's, the DTLCC model multiples each failure rate (which is estimated from laboratory conditions) by a maintenance demand rate (MDR) factor to account for the more rigorous operating conditions of the B-1. The MDR factor of each LRU is regarded as a function of the location and utilization of the LRU, and remains unaffected for both new design and retrofit modifications.

The B-1 is supported by a three-level (organizational, intermediate, and depot) maintenance concept; however, each of the LRU's examined in FOCAP is sent to depot for less than 2-percent of its total maintenance demands. It is assumed, therefore, that all LRU repairs occur at intermediate level. Since both the new design and retrofit interface units are replaceable "cards," the conversion to fiber optics does not affect the 100-percent intermediate repair assumption.

Both organizational and intermediate repair times are assumed to be unchanged in this study. Organizational maintenance (detect, isolate, remove, and replace) is a function of the location of the LRU, which is not affected by the interface units. The intermediate repair time, which involves the removal and replacement of cards inside the LRU, is not a function of the individual bits and pieces on each card, and is also assumed to be constant.

Other assumptions in this study were that the average material cost per intermediate repair can be estimated as 0.1 percent of the unit cost of the LRU, and that 1 percent of all LRU maintenance demands result in condemnations of the LRU (except for LRU's with a unit cost over $200,000, which assumed a 0.5-percent condemnation rate).

Added/Deleted LRU's

For existing LRU's deleted in the Super-MUX designs, reliability and maintainability factors were obtained from B-1 reliability and logistics groups. For the added LRU's in the 8-MUX and Super-MUX designs, reliability and maintainability factors were derived by complexity estimates and analogy with existing electronic boxes.

Wire and Fiber Optics Cables

Wire failure data taken during the B-1 flight test program were adjusted to reflect what would be expected during steady-state operations. A failure rate of 0.63 failures per million hours resulted. A maintenance demand rate factor of 1.96 is used to add the additional maintenance demands other than failures (e.g., human errors resulting in a wire segment break). This value was also extracted from B-1 flight test data. Fiber optics cables are assumed to have the same reliability.

On all subsystems except the DSG, the repair times for wire and fiber optics cables were based on the manufacturing estimates. It is assumed that the on-aircraft repair times are 1.6 and 2.1 man-hours per wire segment and fiber cable segment, respectively. The average material cost per repair (i.e. replacing the damaged segment) is estimated by multiplying the average length (of wire or fiber cable) per segment (including overbuy) times the price per foot.

The DSG is somewhat more complicated, containing many multichannel, multistub data buses. The multistub buses wire cables, due to their complexity and fabrication techniques, are repaired as a unit, precluding individual wire segment repair. If breakage occurs between any two stubs the total bus cable interconnecting all the stubs must be replaced. The DSG also has more difficult access than the other subsystems, especially since some of the cables are buried behind flight instruments.

The mean remove and replace time on the DSG for wire is estimated at 142 man-hours, and the average material cost per segment repair at $5,700. For fiber optics, the difficult access problem remains; however, each individual fiber cable can be replaced without affecting nearby cables due to the simpler fabrication process. For the fiber optics DSG, the mean remove and replace time (including access) is estimated at 62 man-hours, and the mean material cost per fiber cable repair is estimated by multiplying the average length of the cable (including overbuy) times the price per foot, giving estimates of $38 and $21 for the daisy chain and star coupler designs, respectively.

General Cost Factors

The LCC evaluations required a variety of general cost factors associated with the production and deployment of a large strategic aircraft such as the B-1. Certain of these items were established from a review of corresponding B-1 values, and others were derived from Government publications (References 9 and 15). Table 36 presents a list of these factors as applied to the FOCAP study. The cost factors are for comparative purposes only and do not constitute a commitment on the part of Rockwell. These factors are subject to change.

RESULTS OF LIFE CYCLE COST EVALUATIONS

The data described previously were input to the DTLCC model to determine the B-1 LCC for the candidate wire and fiber optic data transfer subsystems. The results of these computer runs for the new design fiber optics concepts are summarized in Table 37. It should be noted that these life cycle costs represent the LCC contributions of the removed wire and added fiber optics components and do not represent the total LCC of the B-1. The life cycle costs have been divided into RDT&E, acquisition, and O&S cost categories. A 10-year steady-state operational period was used in developing these life cycle cost estimates. All costs are in constant 1977 dollars and are computed for a production lot of 240 aircraft. Reference 16 contains the actual computer outputs from these evaluations.

Several conclusions can be drawn from the data presented in Table 37. The DSG, EMUX, and Super-MUX result in B-1 LCC savings. The potential cost savings for the two Super-MUX designs are $187 million (daisy chain) and $184 million (star-coupler). However, these savings are based upon cost estimates of new computers and new data acquisition units, and thus there is some uncertainty in the projected cost delta. The DSG appears quite promising, for it is estimated that the new design daisy chain concept would yield an LCC savings of $100 million in return for an RDT&E investment of less than $6 million. The new design EMUX concept also leads to some cost benefit, but the savings is not as large relative to the RDT&E investment. The 8-MUX

TABLE 36. GENERAL COST FACTORS USED IN LCC EVALUATIONS

Factor	Value
Manufacturing support hours as a fraction of direct manufacturing labor hours	0.3903
Manufacturing support dollars per man-hour	20.0
Engineering support hours as a fraction of basic engineering hours	0.3586
Total annual flight hours per unit equipment (UE) aircraft	329.14
Total number of UE aircraft	210
Total number of production aircraft	240
Base labor dollars per man-hour	16.30
Depot labor dollars per man-hour	23.47
Standard packing labor dollars per pound	0.4065
Standard transportation dollars per pound (for LRU depot movement)	0.0625
Standard ratio of packaged weight to transported weight	1.285
Recurring annual OSE cost as a fraction of initial OSE cost	0.1607
Fuel cost (dollars) per pound of empty weight per UE per year (fixed aircraft)	11.84
Average turnaround time for base repair (months)	0.33
Average turnaround time for depot repair (months)	2.0
Initial OSE cost as a fraction of total flyaway cost	0.034
Material procurement cost (MPC) factor	1.16
Procurement direct expense (PDE) factor	1.06
Contract general and administrative (G&A) factor	1.08
Contract fee factor	1.08

TABLE 37. LIFE CYCLE COST COMPARISON FOR B-1

(New design fiber optics, all costs in millions, FY 1977 dollars)*

Name	Type	Wire subsystem				Fiber subsystem			
		RDT&E	Acqn	O&S	LCC	RDT&E	Acqn	O&S	LCC
DSG	Daisy chain	0	54	63	117	5	9	2	16
DSG	Star coupler	0	54	63	117	6	16	3	25
AMUX	Daisy chain	0	3	1	4	4	4	1	9
AMUX	Star coupler	0	3	1	4	4	7	1	12
EMUX	Daisy chain	0	10	1	11	2	3	1	6
EMUX	Star coupler	0	10	1	11	2	5	1	8
CITS		0	1	<0.5	1	3	1	<0.5	4
8-MUX		0	67	13	80	7	270	43	320
S-MUX	Daisy chain	0	1,100	200	1,300	30	840	250	1,120
S-MUX	Star coupler	0	1,100	200	1,300	30	840	250	1,120

*All cost numbers have been rounded off.

TABLE 38. LIFE CYCLE COST COMPARISON FOR B-1

(Retrofit fiber optics, all costs in millions, FY 1977 dollars)*

		Wire subsystem				Fiber subsystem			
Name	Type	RDT&E	Acqn	O&S	LCC	RDT&E	Acqn	O&S	LCC
DSG	Daisy chain	0	49	61	110	5	80	30	115
DSG	Star coupler	0	49	61	110	5	87	31	123
AMUX	Daisy chain	0	3	1	4	4	42	14	60
AMUX	Star coupler	0	3	1	4	4	46	14	64
EMUX	Daisy chain	0	10	1	11	2	36	11	49
EMUX	Star coupler	0	10	1	11	2	38	11	51
CITS		0	1	<0.5	1	2	12	2	16

*All cost numbers have been rounded off.

concept does not yield an LCC savings due to the additional LRU costs that are experienced.

Table 38 represents the B-1 LCC comparisons for retrofit subsystems. In all cases, the retrofit fiber optic design concepts resulted in an increase in B-1 life cycle cost. The LCC increases range from $6 million in the retrofit daisy chain DSG design, to over $55 million for the AMUX retrofit concepts. The basic reasons for the failure of retrofit designs to show LCC savings are the additional costs for LRU adaptations and the smaller weight savings.

The optimal mix of fiber optic configurations for the B-1 is the new design daisy chain DSG and the Super-MUX. Their combined cost savings is almost $300 million, or about 1 percent of total B-1 life cycle cost. However, the Super-MUX concept requires a major engineering redesign effort that introduces both technological and economic risks. Therefore, a low-risk optimum system would be to utilize fiber optics in the DSG and to employ present wire design concepts for the remainder of B-1 data transfer subsystems. Such an approach offers the potential for cost savings of $100 million on the B-1. Table 39 displays the annual operations and support cost savings on the B-1 which are anticipated by this implementation.

If the DSG and Super-MUX concepts were incorporated at the conceptual design stage on a large strategic aircraft, the 593-pound avionics/electrical systems weight reduction per aircraft could result in additional aircraft size and weight reduction. Figure 29 compares the cumulative cost savings for a rubber aircraft to those of a fixed-size B-1. The total RDT&E plus acquisition cost savings are shown as the initial points on the graph, and the accumulated LCC savings are shown as a function of the operational period. The results show that the cascading weight benefits of fiber optics result in a potential 50-percent increase in LCC savings over the fixed-size B-1.

Escalated Cost Comparison

A ground rule of the FOCAP cost analysis was that all LCC data were to be expressed in constant 1977 dollars. An alternative approach would have been to express all costs in "then-year" dollars by escalating the various annual costs to the year in which they are to be experienced. A summation of these inflated annual costs would yield the total life cycle cost in then-year dollars.

One difficulty with this cost analysis technique is that the inflation rate projections can have a profound influence on the cost calculations. Since there is considerable uncertainty in making such projections, a then-year LCC comparison for time periods well into the future can be dominated by possibly erroneous inflation rates. In addition, inflation does not necessarily result in a change in purchasing power, for revenues may rise at the

TABLE 39. DSG ANNUAL SAVINGS TO USAF

(O&S, FY 1977 $ Millions)

	Maint labor	Maint mtl	Trans	Recurring spares	Inspection	Recurring OSE	Fuel & tanker	Total
DSG (wire) costs	1.4	3.5	0.0	0.0	0.0	0.3	1.1	6.3
DSG (fiber) costs	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
Savings	1.4	3.5	0.0	0.0	0.0	0.3	0.9	6.1

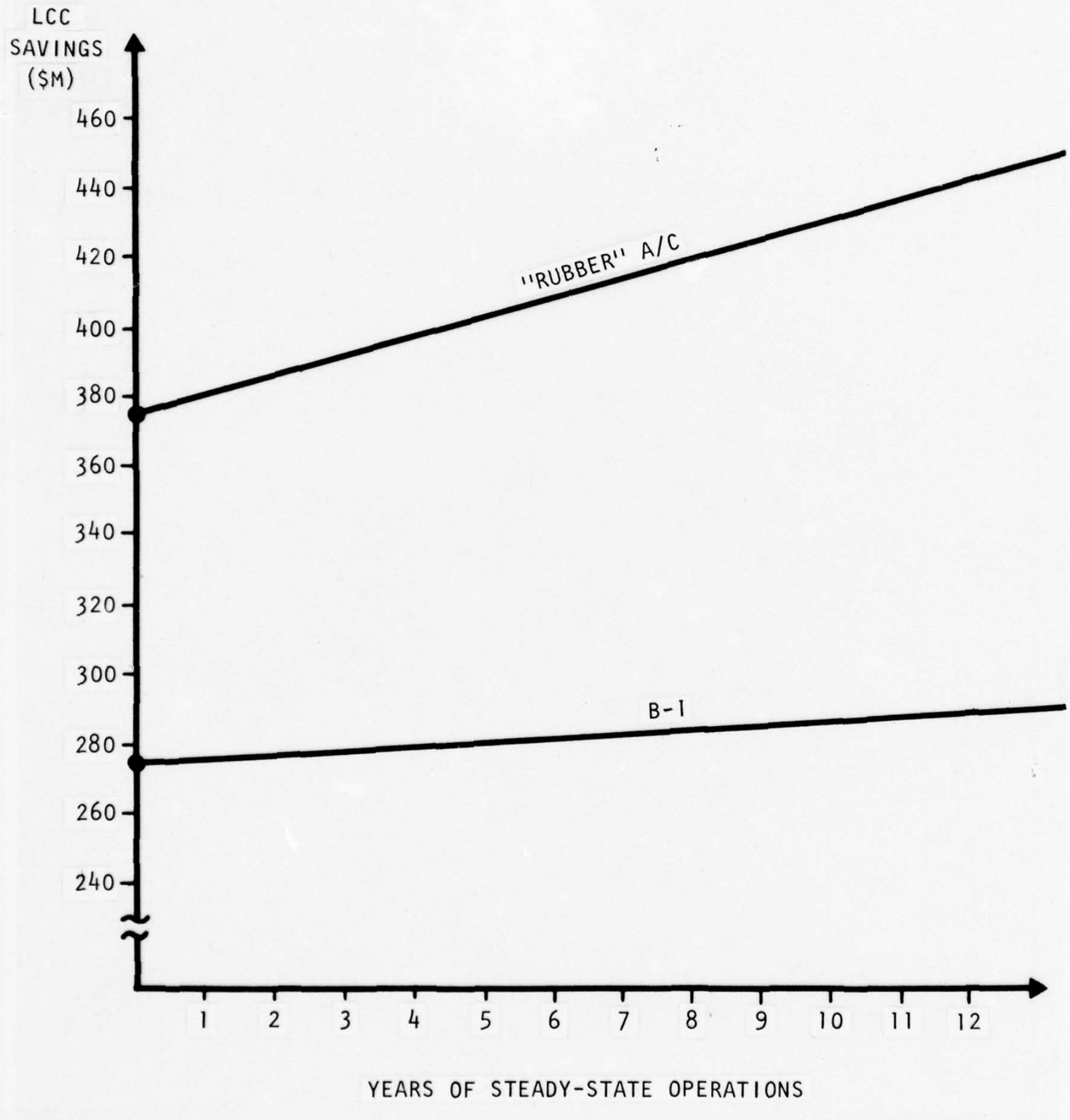


Figure 29. LCC savings for B-1 and "rubber" aircraft fiber optics DSG, Super-MUX (FY 1977 $ in millions).

same rate as expenditures. Under such conditions, the then-year costs are balanced by then-year revenues.

However, the use of then-year LCC analysis is very appropriate when certain elements of cost may experience relative price changes in the future due to supply/demand interaction. A recent example of this economic situation is the growth in fuel prices at a rate well above that of general inflation. If a potential scarcity of a resource can be identified and a constant (or increasing) demand for the commodity is also evident, then the future cost of the item will be higher, assuming it continues to operate in an unconstrained (free) market. Since this relative price change is not attributable to inflation, it is a "real" cost increase when considered against then-year (escalated) funding.

With these guidelines on the advantages/disadvantages of then-year cost evaluations, it is now appropriate to consider such an approach in the FOCAP cost analysis. The B-1 DSG configuration was selected for such an exercise, and an LCC comparison was performed between the wire and new design daisy chain concepts. The procedure used follows:

1. The LCC data (in 1977 dollars) for the two DSG configurations was examined to identify that portion of acquisition cost attributable to the procurement cost of wire or fiber optic cable. These costs were then adjusted using A-7 ALOFT study price projections (NELC/TR 1982, 1 March 1976) to consider the future relative price difference between wire and fiber optic cable.

2. All other costs were escalated using standard inflation rate tables provided in the USAF planning factors manual (AFR 173-10, September 1976). Midpoint years were selected for the RDT&E, acquisition, and operations and support time periods, and all associated costs were escalated from 1977 dollars to the specified midpoint then-year. The mid-point years were assigned as follows:

RDT&E	1977 (current year)
Acquisition	1982
Operations & support	1987

3. The results of items 1 and 2 were combined to determine then-year LCC for the two configurations, and these results were compared to the 1977-dollar results as computed by the DTLCC model.

Reference 16 (the ALOFT report) projected a substantial rise in the price of copper wire during the next few years. These data were used to establish a procurement cost of $3.00 per foot for wire in 1982 (midpoint of B-1 acquisition program). This roughly a 10-fold increase to the price being used in the 1977-dollar LCC analysis. The ALOFT report also projected a rapid

decrease in fiber cable costs due to the increase in production and the almost infinite supply of the basic resource for its manufacture. An estimate was made that the combined effect of increased demand countered by inflation would result in a 1982 price of $1.60 per foot for the 19-fiber bundle being used in the FOCAP designs. The 1977 price is estimated at $2 per foot. Both the wire and fiber optic cable prices reflect procurement quantities required for the full B-1 production program.

The results of this investigation are displayed in Table 40. LCC contribution in 1977 dollars and then-year dollars are shown for both configurations, along with the corresponding cost deltas. Note that the numerical cost savings with fiber optics increased from $100 million to $250 million in converting from 1977 dollars to then-year dollars. The order-of-magnitude jump in wire cable price used for the then-year analysis is the cause for the large difference in then-year acquisition cost. A similar exercise using the rubber-aircraft approach gives a then-year cost delta of $383 million, as compared to $193 million in 1977 dollars.

Life Cycle Cost Summary

The preceding cost data indicate that fiber optic technology does offer the potential for cost savings on large military aircraft. These savings can be realized on individual data transfer subsystems which operate at high data rates (e.g., DSG), or through optimal combination of subsystems to take full advantage of the bandwidth capability of fiber optics (e.g., Super-MUX). The cost reductions for the implementation of fiber optics into the DSG for both the fixed-sized B-1 and a rubber aircraft, in constant-year and then-year dollars, are shown in figure 30. The corresponding potential cost savings for the DSG and Super-MUX are shown in Figure 31.

TABLE 40. SUMMARY COST COMPARISON FOR B-1 DSG

(New Design, Daisy Chain Fiber Optics Concept)

Cost category	Wire ($M)		Fiber optics ($M)		Delta ($M)	
	$ 1977	$ Then-year*	$ 1977	$ Then-year*	$ 1977	$ Then-year*
RDT&E	0	0	5.1	5.1**	+5.1	+5.1**
Acquisition	53.5	178.0	9.2	9.0	-44.3	-169.0
Operations & Support (10 years)	63.2	98.0	2.4	3.7	-60.8	-94.3
Total	116.7	276.0	16.7	17.8	-100.0	-258.2

* Effects of inflation considered.
**Midpoint assumed to be the year 1977.

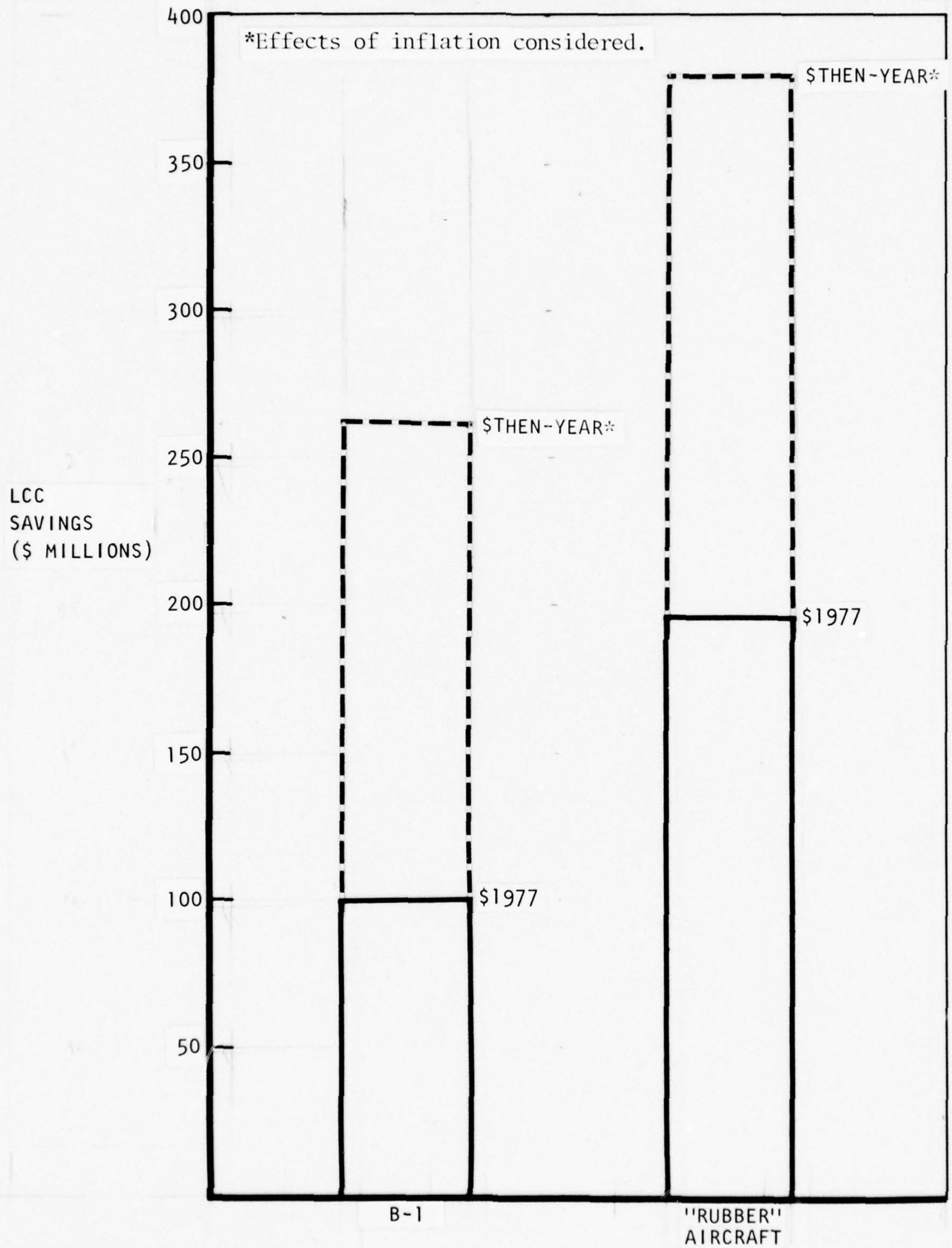


Figure 30. Summary of LCC savings due to fiber optics (new design daisy chain DSG configuration).

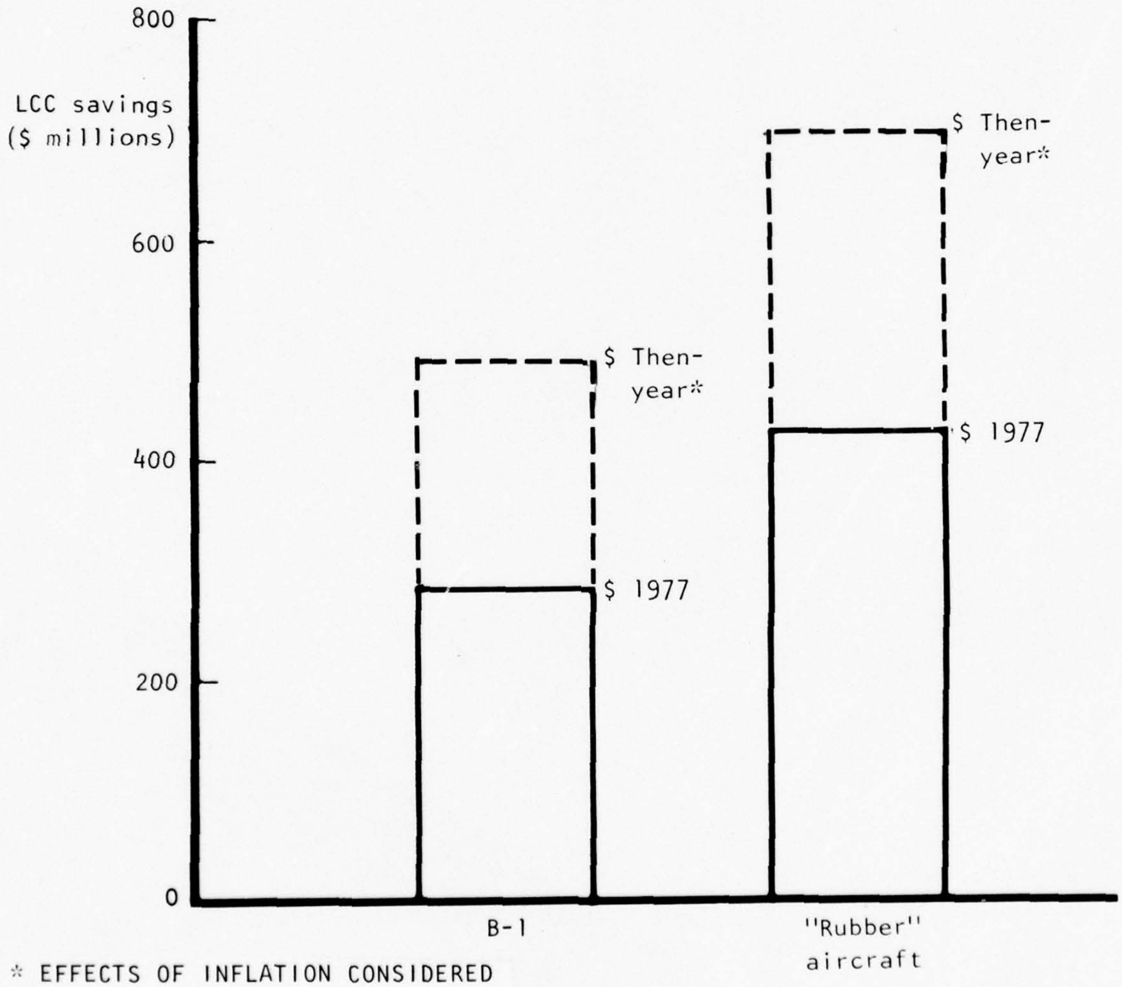


Figure 31. Summary of LCC savings for DSG and Super-MUX (new design daisy chain configurations).

Section V

SENSITIVITY ANALYSIS AND TRADE STUDIES

GENERAL

One of the major objectives of the FOCAP study was to identify those design and cost parameters which have the greatest influence on the contribution of data transfer subsystem components to aircraft life cycle costs (LCC). In order to accomplish this goal, a series of sensitivity analyses were performed using the DTLCC model, and the results plotted. Examination of these graphs yielded a prioritized list of cost drivers which are candidates for future technical research. They also provided a tool for assessing the economic risk due to uncertainties in the baseline value(s) assigned to input parameters. A variety of cost trade-offs were also addressed in the FOCAP study to identify trends in the cost benefit of fiber optics application.

The sensitivity studies were performed through parametric evaluations on the fiber optic subsystem design(s) which displayed potential cost savings on the B-1. Cost trade-offs were made through examination of the costs associated with specific subsystem performance features (EMI, bandwidth, etc), or through definition and LCC analysis of design concepts with different performance levels.

SENSITIVITY STUDIES

Parametric evaluations were performed on those fiber optic design concepts which offer potential LCC savings to determine the relative cost impact of system variables. The following paragraphs delineate the sensitivity analysis results and describe the effect on B-1 LCC savings.

CABLE COSTS

There is some uncertainty in the procurement cost for fiber optic cable due to the questionable future demand for the fibers. The cost for wire cable may also vary in the future if the availability of copper becomes reduced. To determine the cost impact of changes in fiber and wire costs, the new design daisy chain DSG configuration was parametrically evaluated as a function of the respective unit costs. Figure 32 displays the results of this analysis, presenting LCC savings as a function of fiber optic cable cost per foot. Isocurves are provided for the wire cost of $0.33 (baseline) and $1 per foot to demonstrate the LCC sensitivity to combined changes in the unit costs. For instance, if both fiber and wire cable costs were equal to $1 per foot, the DSG daisy chain would save $36 million in addition to the $100 million of the

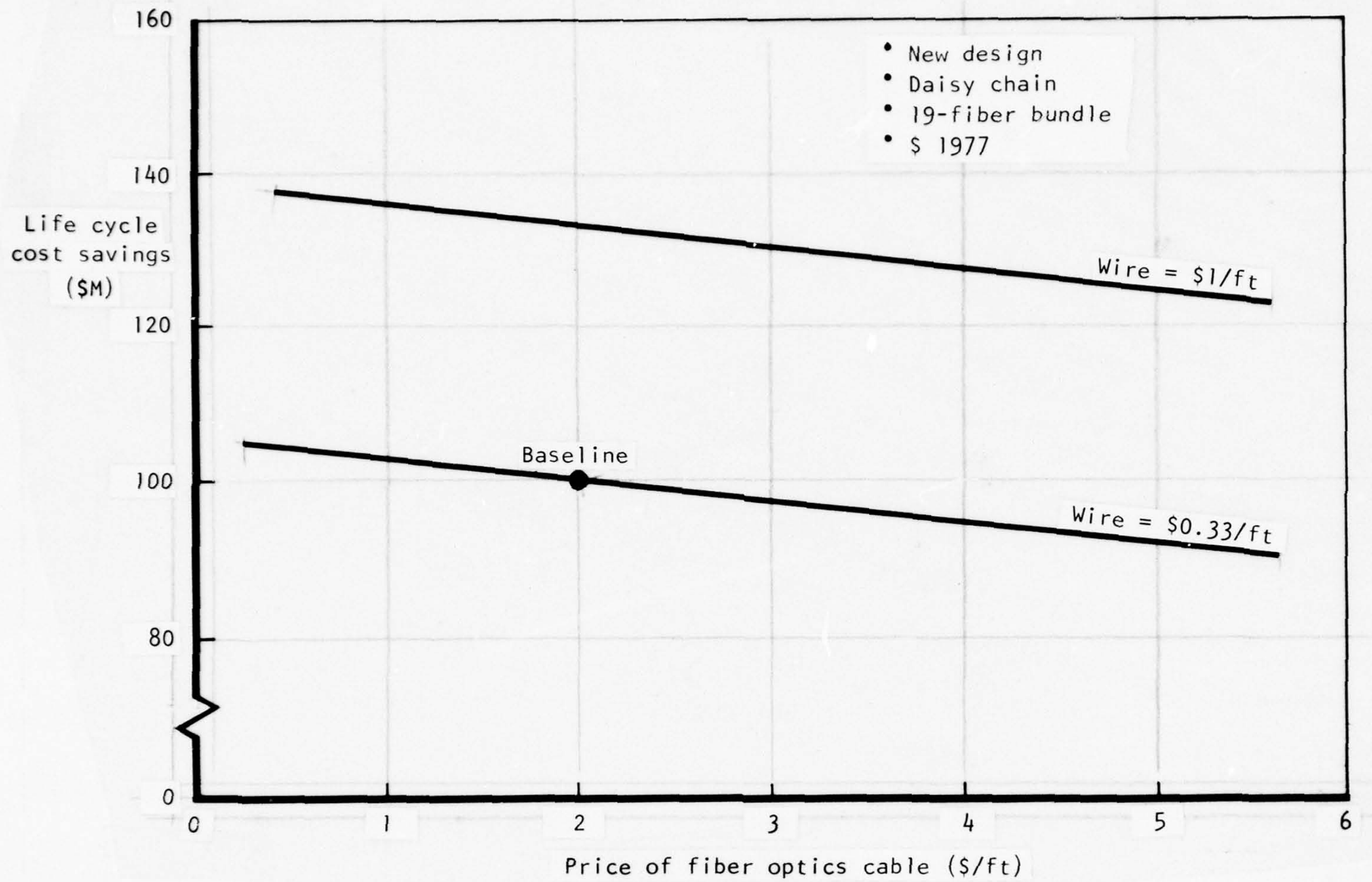


Figure 32. DSG, effect of cost of wire and fiber optic cable on LCC savings.

baseline. Such a variation in cost savings implies the ratio of the procurement cost of fiber cable to copper wire is a significant cost driver.

To explore the cost impact of fiber cable price on other B-1 subsystems, the new design daisy chain EMUX concept was also evaluated. The results, shown in Figure 33, indicate that if the cost of fiber cable doubles from the baseline case of $2 per foot, the LCC savings for this EMUX concept will be reduced by $2 million (about 40-percent reduction in LCC).

SEGMENT PREPARATION AND INSTALLATION TIMES

A considerable savings in aircraft acquisition costs may result if fiber optics is substituted for wire cable due to the large reduction in segment preparation and installation times. This is especially true in the DSG configurations, where the segment count can be reduced 18-fold through implementation of fiber cables. First aircraft man-hour standards were derived for both wire and fiber optic cable tasks (see Section IV). These first aircraft man-hour standards were then extrapolated on appropriate learning curves to establish fleet cumulative average man-hours per segment installation, resulting in 0.645 and 0.85 man-hours, respectively.

Sensitivity of LCC savings on the DSG to the average man-hours per preparation and installation for fiber optic segments is displayed in Figure 34. The functional relationship is shown for fiber cable costs of $2 per foot (baseline) and $5 per foot to demonstrate the combined sensitivity of procurement expense and ease of installation for fiber cable.

SUPER-MUX COMPUTER COST/RELIABILITY

Two new computers are required for the Super-MUX configurations. Engineering estimates of their average unit cost and mean-time-between-failure (MTBF) were extrapolated from the cost and reliability of existing computers in the B-1 EMUX, CITS, and AMUX systems. To determine the sensitivity of the LCC savings for Super-MUX to the cost and MTBF of the computers, a series of parametric runs was made for the daisy chain Super-MUX using the DTLCC model. The model outputs were then plotted as shown in Figure 35. The graph indicates that both factors have a significant effect on the LCC savings. Sensitivity runs for the effect of the procurement costs of fiber optics cable on the LCC show their effect to be secondary to computer cost. Thus, it can be concluded that when new, relatively complex data transmission subsystem concepts require the application of fiber optics, the cost of the electronic line replaceable units (LRU) and their associated failure rate should be given the greatest emphasis in cost benefit comparisons.

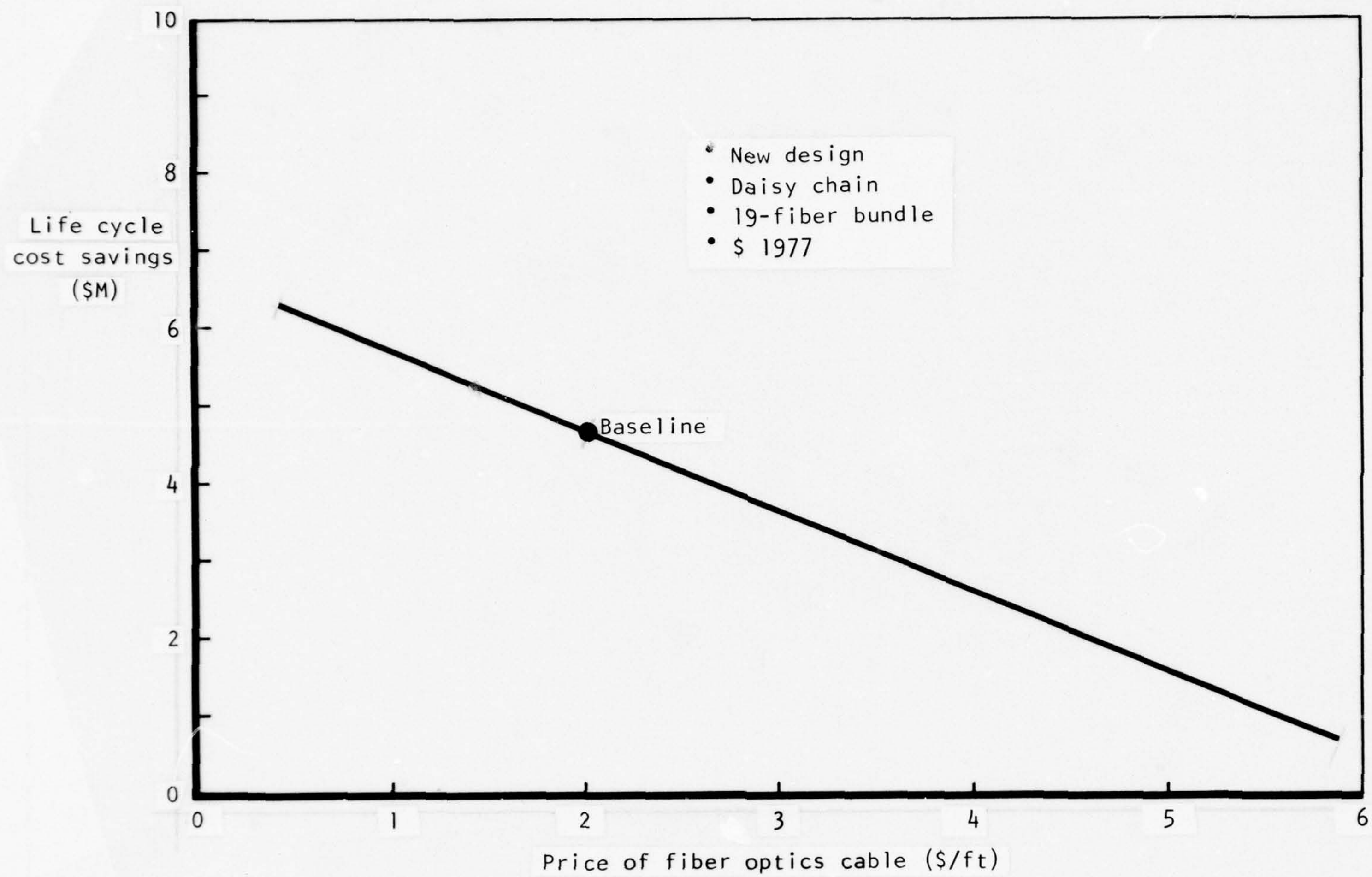


Figure 33. EMUX - effect of cost of fiber optic cable on LCC savings.

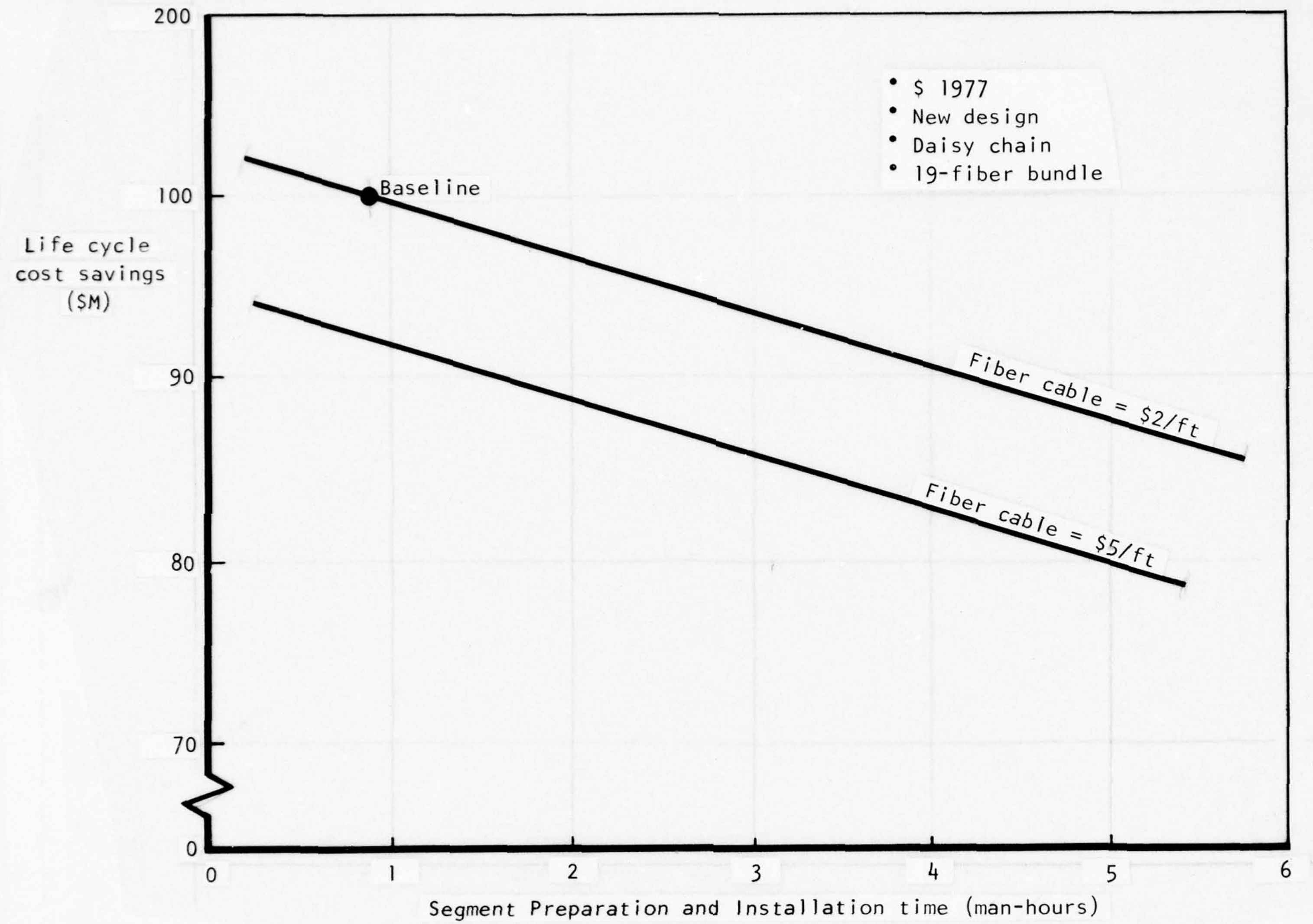


Figure 34. DSG - effect of fiber cable preparation and installation time on LCC savings.

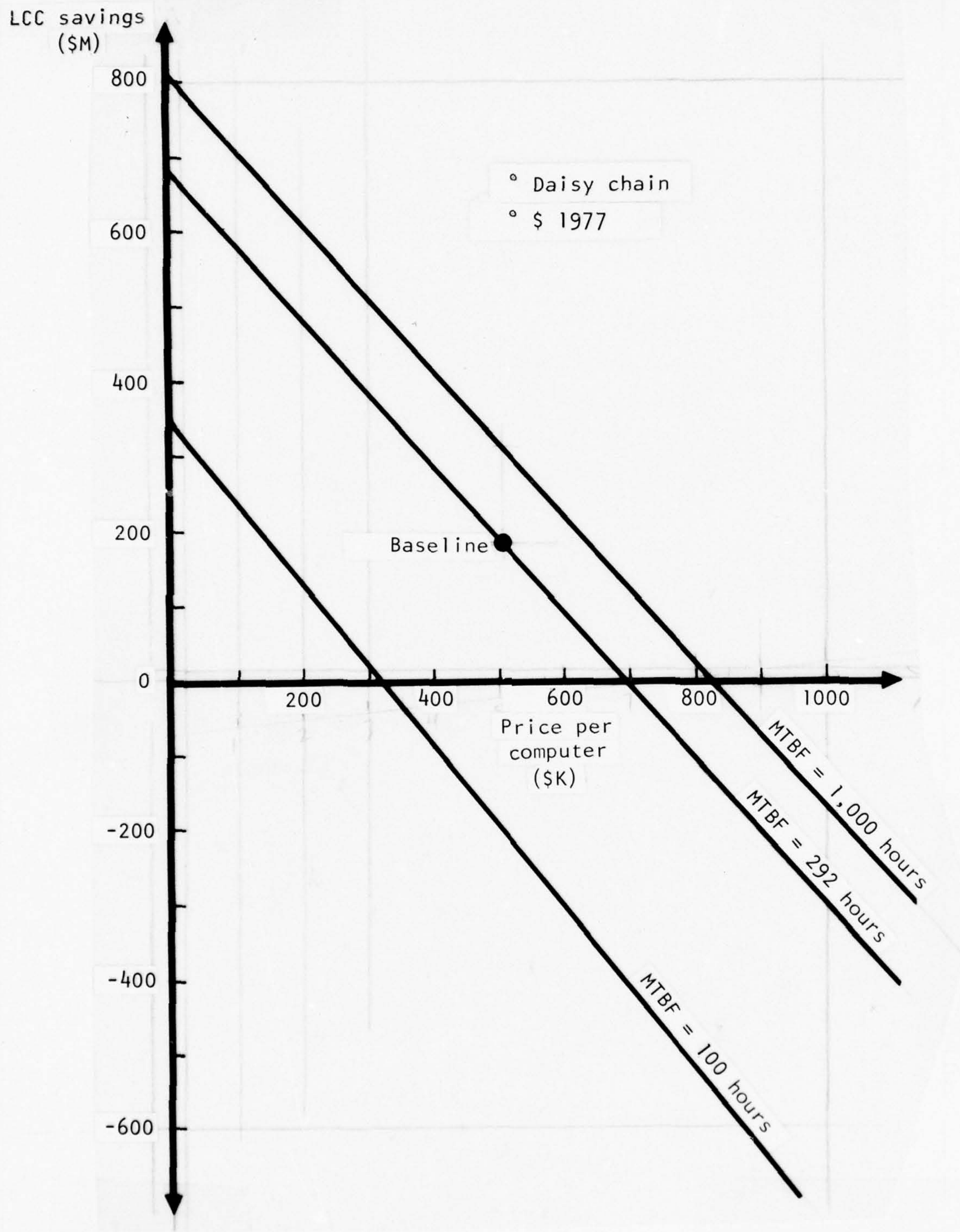


Figure 35. Super-MUX - effect of computer cost and reliability on LCC savings.

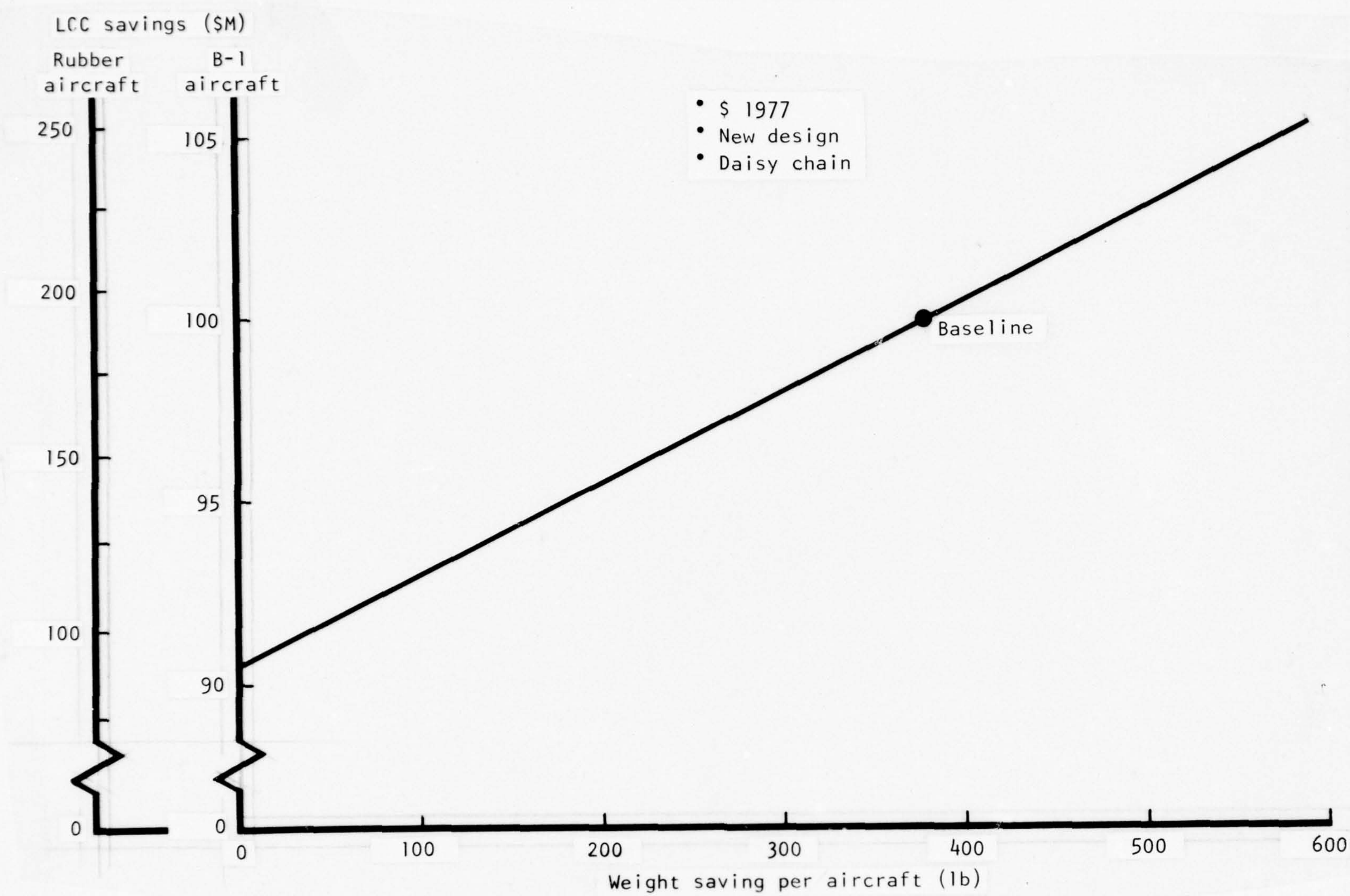


Figure 36. DSG - effect of weight reduction on LCC savings.

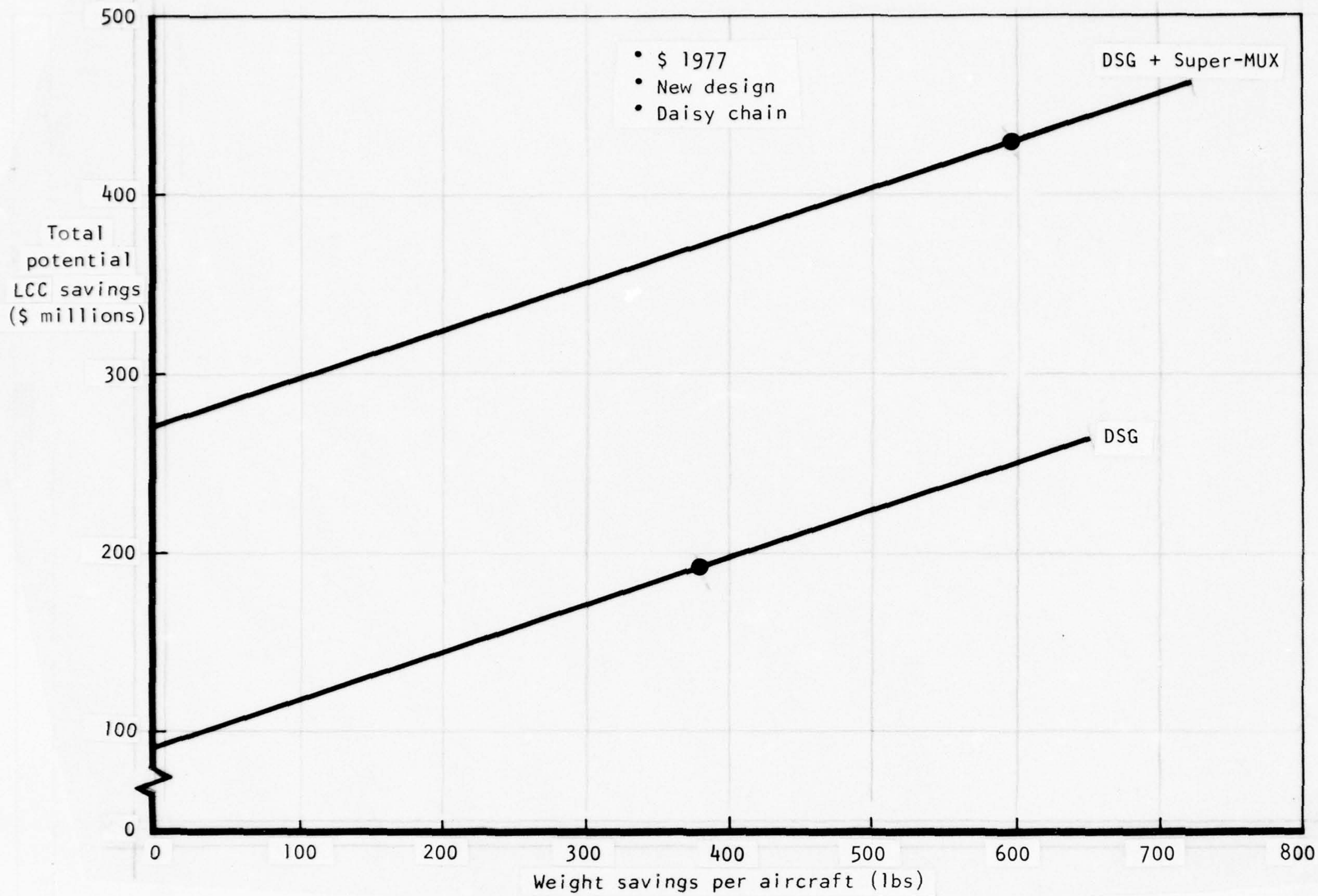


Figure 37. Effect of weight reduction on LCC savings for a "rubber" aircraft.

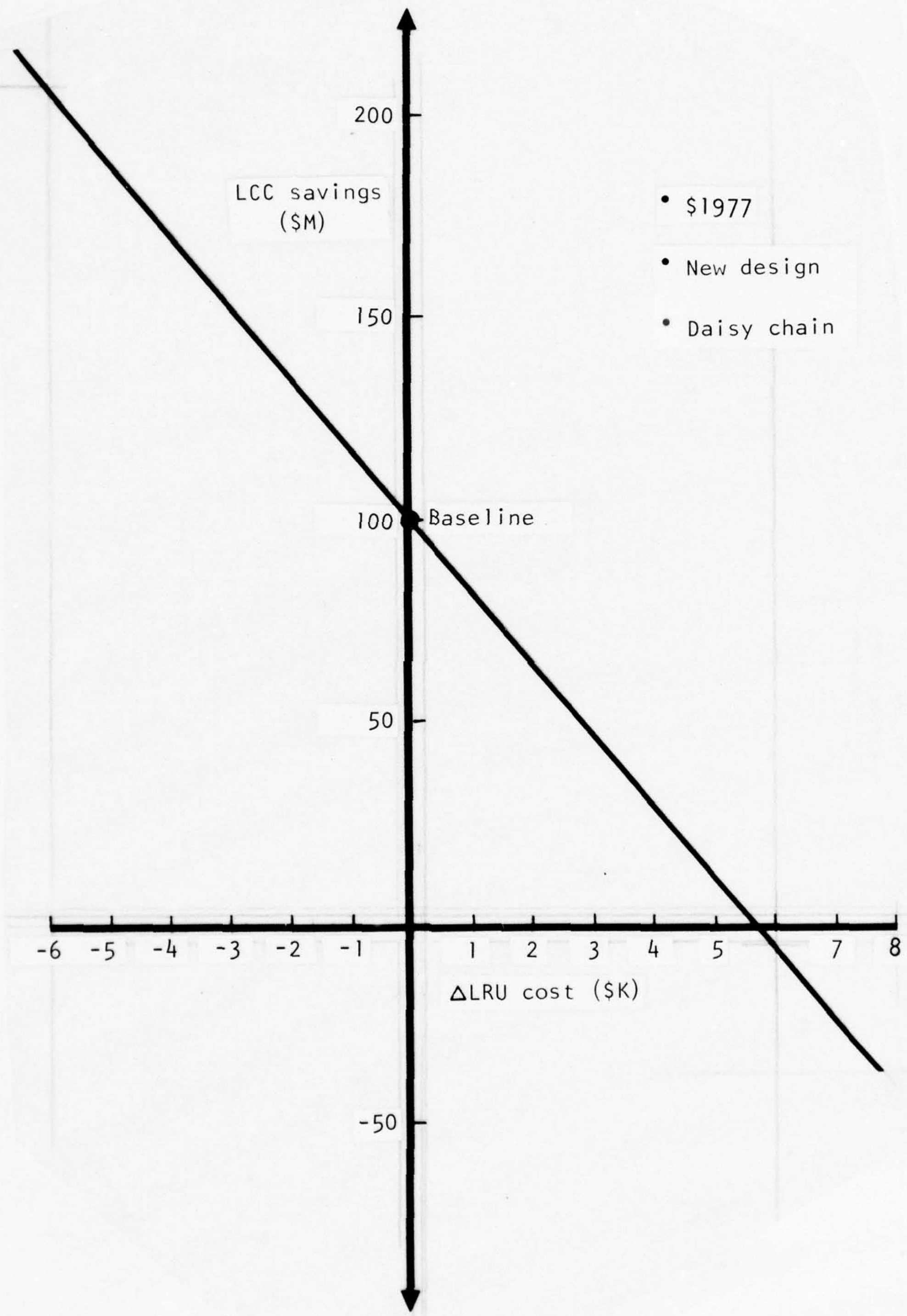


Figure 38. DSG - LCC savings versus ΔLRU cost.

SUBSYSTEM WEIGHT

For the fixed B-1 aircraft, weight savings attributable to fiber optic configurations resulted in a cost reduction for fuel and tanker support. The cost savings per pound of weight decrease per aircraft was determined to be $118.40 for a 10-year operational period. For the new design daisy chain defensive subsystem group (DSG) configuration, the weight savings of 380 pounds results in a $9.5 million cost reduction. The combination of DSG and Super-MUX results in a weight saving of 593 pounds and, therefore, a cost reduction for fuel and tanker support of $14.7 million.

Figures 36 and 37 display the sensitivity of weight savings to LCC for the fixed B-1 and for a "rubber" aircraft.

The combined LCC savings of DSG and Super-MUX, attributable to weight decrease, equal $432 million, when the designs are incorporated during the conceptual design phase of a large strategic aircraft.

RECURRING LRU ADAPTATION COST

Engineering assessments of the recurring cost deltas associated with LRU adaptation to fiber optic data transmission on the DSG resulted in the following:

Retrofit designs - +$5,100 per LRU

New Designs - 0

Rationale for these cost estimates are contained in Section IV. To establish the sensitivity of LCC to these values, the DTLCC model was exercised for the fixed size B-1. Results of this analysis are presented in Figure 38 for the new design DSG daisy chain configuration. The plot indicates that the net change in LRU costs due to fiber optic conversion is a significant cost parameter. If the cost delta were to vary by $1,000 per LRU, the LCC savings would change by 17 percent.

In the approach taken in this study, LED's and photodiodes were considered two of many electronic components comprising the electronics adaptations. As such, their price impacts on that of the adaptations was considered in the adaptation cost estimates, but their prices were not specifically identified in the cost model. The sensitivity of the subsystem LCC to the photodiode and LED costs can be considered in the context of the LRU cost sensitivity.

The Spectronics SPX1775 LED and SPX1777 photodiode used in the conceptual designs of this study are priced at $100 and $90 each in lots of 1,000. With some of these types of components selling in the $5 range, the $110 and $90 prices should be considered worst case. A more typical price of $50 each

was used as a baseline. The typical DSG electronic interface cost attributable to LED's and photodiodes is $300. A 50-percent reduction in the price of LED's and photodiodes could reduce the cost of the electronic adaptations by $150. This cost reduction would result in an additional LCC savings of $3 million, as can be derived from Figure 38.

RELIABILITY/MAINTAINABILITY

There is a significant difference in costs associated with reliability/maintainability of the wire and fiber optic DSG configurations. This is the result of two basic items:

1. The substantial reduction in segment count (and volume occupation) for the fiber optic DSG.

2. The EMI/EMP protection levels require the discarding of entire DSG wire harnesses due to the failure of one specific wire segment. This problem is eliminated by the dielectric fiber cables.

The net result is that cable maintenance becomes a minor cost element (2 percent) of the fiber optic configurations LCC. For the corresponding wire designs, this cost category accounts for over 40 percent of the data transfer subsystem LCC.

Nominal values were assigned to the failure rates and repair times of DSG cable segments. To examine the sensitivity of LCC to these parameters, the wire DSG configuration was analysed for varying MTBF and MTTR values. The results are displayed in Figures 39 and 40, respectively. For reference, the total LCC for the fiber optic DSG has also been indicated in Figure 39 to demonstrate that regardless of the wire segment failure rate, there is always an LCC savings for fiber optics in the DSG. Similar data for the fiber optic configurations have not been provided due to the small contribution of cable maintenance to LCC.

COST TRADE-OFFS

The preceding sensitivity data have displayed the variation in LCC for discrete parameters in cost evaluations. The following paragraphs address more general comparisons of the cost benefit of fiber optics.

COST VERSUS VULNERABILITY PROTECTION

The vulnerability protection costs on the B-1 can be divided into the costs associated with electromagnetic interference (EMI) and those associated with transient radiation effects on electronics (TREE).

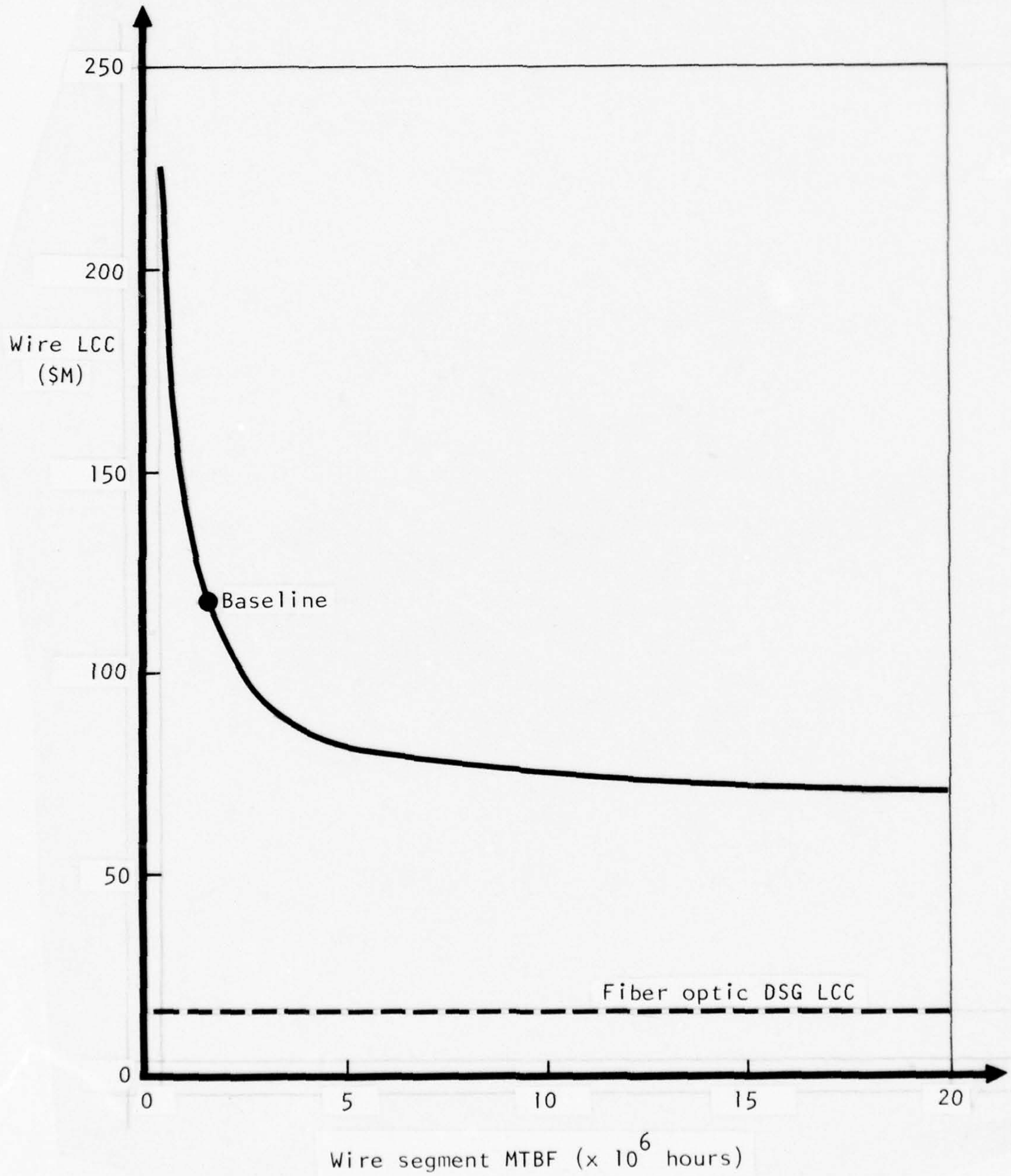


Figure 39. Impact of wire segment MTBF on LCC (FY 1977 $ millions).

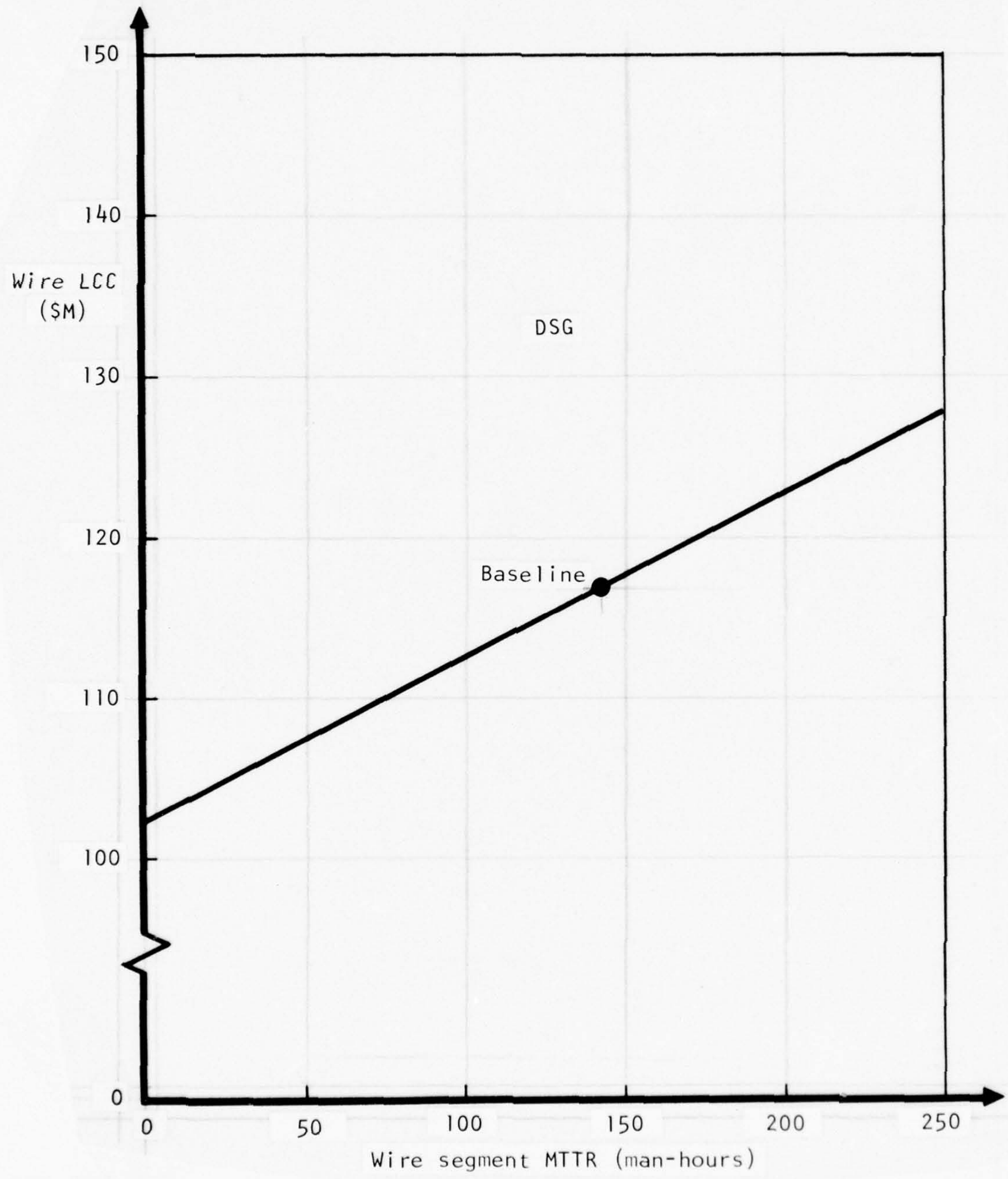


Figure 40. Impact of wire segment MTTR on LCC (FY 1977 $ millions).

Selection of the 19-fiber fused silica, plastic clad cable used in the FOCAP designs was influenced by the Transient Radiation Effects on Electronics (TREE) hardening requirements of the B-1 system. Less expensive fibers could be used if these specifications did not exist. If the cost of fiber cable could be reduced from $2 per foot to $1 per foot due to procurement of non-hardened cable, the LCC would decrease by $2.4 million (15 percent) for the fiber optic DSG. Thus, the TREE protection level requirements of the B-1 aircraft system have a minor impact on the total LCC.

EMI protection is governed by MIL-STD-461A(3), Test Method RE02 Specification. To assure adherence to the MIL-STD-461A(3), overbraid and protective conduit are used on many of the wire cables.

The elimination of protective conduit and overbraid through substitution of fiber cables for conventional wire is a source of cost savings. For the B-1 DSG configuration, the combined effect of procurement cost savings for conduit (20.5 lbs) and overbraid (56.1 lbs) and weight reductions of 77 pounds per aircraft results in a B-1 LCC savings of $3 million for the new design daisy chain configuration (3 percent of total LCC savings). If these weight savings were credited to a "rubber" aircraft, the LCC savings would be $22 million.

It should, however, be noted that at the present time the B-1 EMUX system exceeds the EMIC radiated emission limits of MIL-STD-461A(3) by up to 30 db over the frequency spectrum of 0.9 to 350.0 MHz. The wires that carry the thousands of discrete input and output signals for EMUX are the source of these out-of-specification emissions. Rockwell, Harris (EMUX supplier), and the B-1 SPO technical consultant of EMIC agree that the only way to eliminate this nonconformance, without totally unacceptable LRU weight and volume increase, is to shield all discrete A/C-4 EMUX signals. A study was performed by Rockwell in November/December 1975 (Reference 18) to assess the weight impact of shielding all aircraft 4 discretes. The projected weight increase was 900 pounds.

The B-1 operates satisfactorily without these shields, and the B-1 System Safety Office has agreed to modify the EMUX MIL-STD-461A(3) RE02 requirements. The ability of the B-1 to operate satisfactorily with those nonconformances is the result of the following design features for the electrical/electronic systems. These features generate balanced circuits in the aircraft, with inherent rejection of common mode (EMIC) noise and a low-noise environment.

1. Circuit returns - all power and signal circuits have wired returns. There is no deliberate current flow in the structure.

2. Grounding - There is a true single-point ground for all power circuits. This applies to 230 vac, 115 vac, and 28 vdc. The signal common for all LRU's is grounded adjacent to the LRU.

3. Power input - Power input for all LRU's (GFE excepted) is by isolation transformer. Step-down devices (T-R units, transformers) for GFE have isolation transformers at the 230 vac input.

4. Input circuits - All receive circuits (GFE excepted) are balanced with respect to signal common (digital, analog, and discrete).

5. Wiring - All circuits that do not use coax, triax, or waveguide are either twisted or shielded and twisted.

It therefore is not likely that strict adherence to MIL-STD-461A(3) will ever be required. If, however, conformance to this specification is required on any future strategic aircraft, the additional weight impact of 900 pounds can be avoided by using fiber optics instead of the conventional wires. This 900-pound weight penalty would result in a potential LCC saving of about $250 million (1977 dollars).

COST VERSUS BANDWIDTH

In order to analyze the cost/bandwidth trade-offs, a "1 mb/sec DSG" was conceived. The 1 mb/sec DSG assumes that the data rate transfer requirement on the DSG is such that all data on each cable could be multiplexed over one 1 mb/sec data channel. The number of bulkheads penetrated, LRU terminations, etc, remain the same as for the 40 mb/sec subsystem.

Configuration data for the wire and fiber optics concepts for a 1 mb/sec DSG are delineated and compared to the present 40 mb/sec DSG systems in Tables 41 and 42, respectively. The data were used as input to the DTLCC model. The LCC results were combined with the LCC results for the baseline 40 mb/sec DSG system and are plotted in Figure 41. Linear extrapolation was made to 100 mb/sec. This linearity is projected based upon the following:

1. Segment count and subsystem weight are major cost drivers.

2. Both are proportional to the total system bandwidth above a technological threshold. The wire subsystem is capable of operating at a data rate of 1 mb/sec per channel. As previously explained, a fiber optics capability of approximately 20 mb/sec per channel is being used in this study. Above these thresholds more channels are added, resulting in a linear increase in segment count and weight.

The conclusions that can be reached are as follows:

1. At data rates of 1 mb/sec, conventional wire subsystems are approximately the same cost as their corresponding fiber optic design. This result is consistent with the previous findings for AMUX, EMUX, and CITS. (Refer to Section IV.)

TABLE 41. CONFIGURATION DATA FOR 1 MB/SEC AND 40 MB/SEC WIRE DSG CONCEPTS

	40 mb/sec	1 mb/sec
Wire segments (No.)	7,225	326
Cable length (ft)	79,600	3,770
Bulkhead connector (No.)	22	1
Conduit (ft)	220	10
Overbraid (ft)	365	18
Wire weight (lb)	345.9	16.4
Bulkhead connector weight (lb)	7.2	0.3
Conduit weight (lb)	20.5	1.0
Overbraid weight (lb)	56.1	2.7
Total system weight (lb)	442.1	32.8

TABLE 42. CONFIGURATION DATA FOR 1 MB/SEC AND 40 MB/SEC FIBER OPTIC DSG CONCEPTS

	40 mb/sec	1 mb/sec
Cable segments (No.)	400	166
Cable length (ft)	6,800	2,820
Bulkhead connectors (No.)	14.5	6.0
LRU connectors (No.)	58	58
Fiber cable weight (lb)	48.3	20.0
Bulkhead connector weight (lb)	3.8	1.6
Total system weight (lb)	61.5	31.0

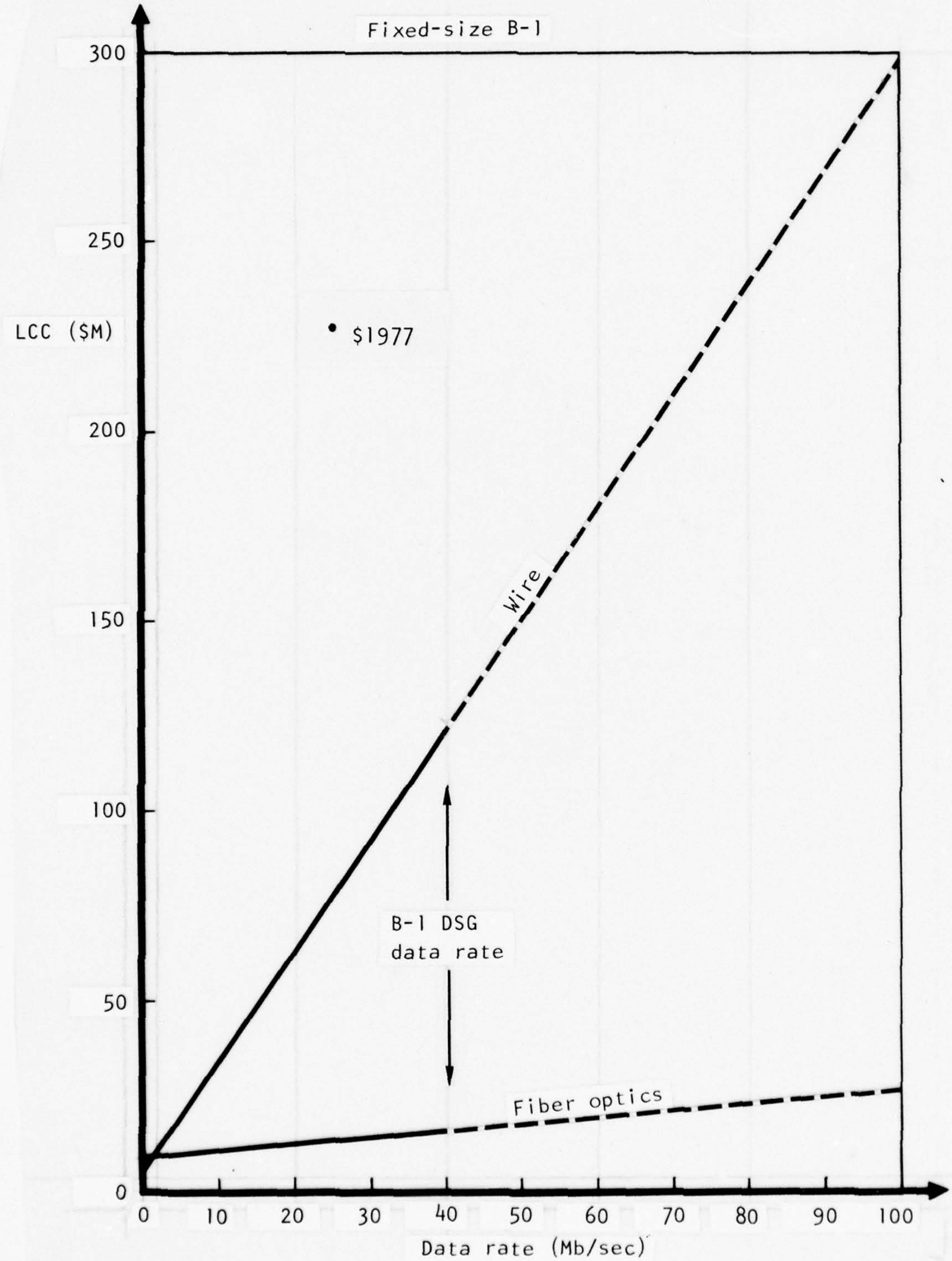


Figure 41. Bandwidth cost trade-off.

2. At data rates in excess of 2 to 3 mb/sec, fiber optics show a cost advantage. Generally, two to three wire channels are required for each fiber optic channel.

3. The cost projection to data rates of 100 mb/sec shows a savings of about $275 million for the fixed-size B-1 aircraft and about $525 million for the rubber aircraft (1977 dollars).

It should, however, be noted that there is at the present no known requirement to transmit data at rates of 100 mb/sec.

WEIGHT VERSUS BANDWIDTH

The wire and fiber optics subsystem weight for the 1 mb/sec and 40 mb/sec configurations are plotted in Figure 42. Again, a linear extrapolation has been made to data rates of 100 mb/sec.

To quantify the potential cost impact of the subsystem weight delta, consider a future large strategic aircraft which utilizes 100 mb/sec data rates. The projected weight savings if fiber optics are employed for data transmission is approximately 1,000 pounds per aircraft. Such weight reductions translate into LCC savings due to weight of about $270 million if incorporated during the conceptual design stage of the aircraft system.

COST VERSUS VOLUME OCCUPATION

As shown in this study, replacement of wires with fiber optic links will, in most cases, reduce the volume required for the data transmission system. In addition, the Super-MUX concept, defined in this study, indicates that multiplexed fiber optic links would require fewer black boxes than multiplexed wiring links, due to the higher data rate possible on optical links.

It is believed that any reduction in volume of the internal aircraft systems will result in cost savings for new aircraft. These cost savings fall into three categories.

The first savings comes from a reduction in engineering design complexity resulting from reduced internal density in the aircraft. This results in reduced engineering man-hours during the initial aircraft design and reduces engineering support during fabrication of prototype and production vehicles.

The second savings is reduced manufacturing man-hours during the system installation in the aircraft. This savings comes from reduced system volume to install and also from easier installations resulting from reduced density.

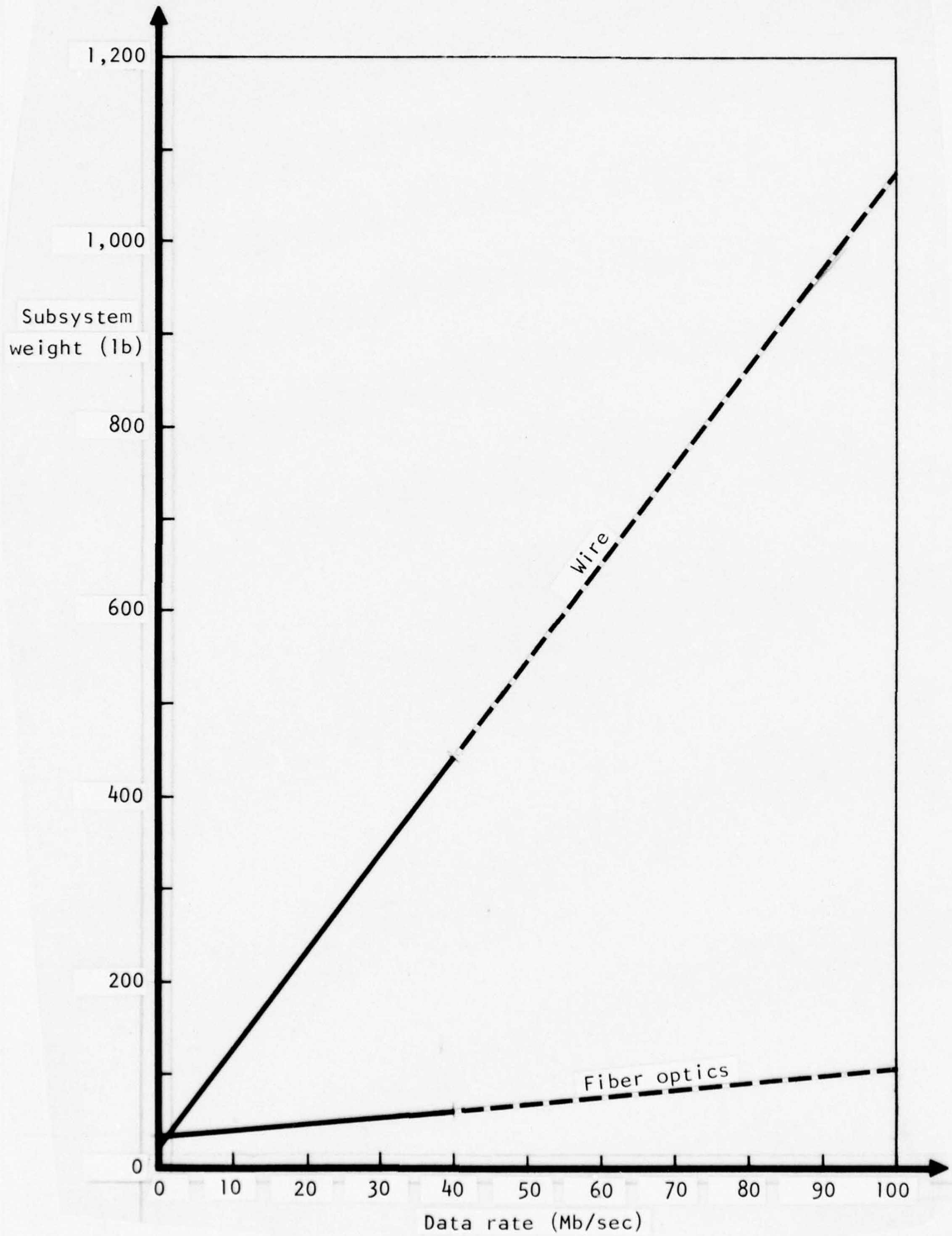


Figure 42. Bandwidth/weight trade-off.

The third savings would result from shrinking the aircraft due to the reduced volume required (rubber aircraft). This savings would be the largest of the three savings. However, it should be noted that shrinkage of the aircraft would also increase the internal density thereby, partially reducing the savings from the first two categories.

Cost savings due to volume were implicit in the weight savings, manufacturing man-hour estimates, and maintainability factors, and thus cannot be directly quantified.

COST SAVINGS ASSOCIATED WITH FIRE HAZARD

In present-day aircraft design, considerable design effort is expended in isolating electrical wiring from fire hazards such as the fuel and oxygen systems. Substitution of fiber optics for wiring would reduce the complexity of routing design, permitting a reduction in engineering man-hours. Here, again, as in the case of cost savings due to volume reduction, the aircraft LCC does not use the complexity of routing design as an input parameter; therefore, this cost cannot be quantified.

COST IMPACT ON POWER CONSUMPTION

For retrofit fiber optics systems, the cost impact on aircraft power consumption as a result of installing fiber optics was examined using the B-1 DSG subsystem as an example. The addition of fiber optics interface adaptations requires approximately 300 watts (0.3 kva). Presently, the B-1 DSG subsystem requires 50 kva input power. The increase in required power as a result of installing fiber optics is less than 1 percent. Because of this small increase, no specific cost impact could be identified.

In the new design fiber optics concepts, the LRU's, as discussed in Section IV, maintain the same size, shape, and weight and consume the same power as in the corresponding wire configurations.

DAISY CHAIN VERSUS STAR COUPLER COMPARISON

As seen in Table 43, the EMUX daisy chain concept is less costly than the star coupler. The same is true for the DSG and Super-MUX subsystems. Although the star coupler designs require less footage of fiber cable, the daisy chain designs have fewer fiber cable terminations, and, hence, have less preparation and installation man-hour costs. The star coupler designs are also more expensive due to the need of a larger number of optical couplers.

TABLE 43. EMUX NEW DESIGN DAISY CHAIN VERSUS STAR COUPLER (FY 1977 $ MILLIONS)

Cost category	Daisy chain ($M)	Star coupler ($M)
RDT&E	2.0	2.0
Fiber cable procurement	1.4	.7
Fiber cable preparation and installation	.7	1.3
Fuel and tanker	.6	.5
End connector procurement	.5	.5
Initial and recurring OSE	.3	.5
Y-coupler procurement	.2	1.4
Sustaining engineering and support	.2	.2
Star coupler procurement		.5
Other	.2	.5
Total	6.1	8.1

Although the daisy chain concept is less expensive than the star coupler, it has one possible disadvantage; i.e., one LRU failure can render an entire bus inoperative for data transmission. The star coupler concept, in which the LRU' transmit data over a central star coupler, does not have this problem. This difference is not a serious consideration, however. The EMUX and Super-MUX subsystems have redundant buses, so no single LRU is mission critical.

The DSG system is composed of 32 buses; they are not redundant. A failure of one LRU would render only this bus inoperative, but it would not affect the remaining buses. For those reasons, the difference in wartime effectiveness (i.e., mission reliability) between the daisy chain and star coupler designs was considered negligible.

ALTERNATE DESIGN CONCEPTS

Two cost trade-off studies were performed through evaluation of alternate fiber optic design concepts for the DSG and Super-MUX. The LCC results of these two analyses provide both cost/risk comparisons plus the analytical base for projections of cost savings of future performance levels of fiber optic subsystems.

High Multiplex Rate DSG Comparison

The baseline DSG fiber optics interface adaptation concepts employ CMOS/SOS technology in up to three parallel channels. If ECL, rather than CMOS/SOS, were to be used, all DSG data could conceivably be transmitted over a single channel. Assessment of state-of-the-art technology based upon discussions with several systems houses indicates that the technological risk is too high to use ECL in a baseline concept. However, for cost trade-off and sensitivity analysis purposes, the optimistic assumption that ECL can be employed in the DSG has been made and the resulting subsystem described in sufficient detail for cost analysis to be performed. It has been assumed that the primary impact of employment of ECL technology is to reduce the number of fiber optics channels. The reliability, weight, dimensions, power consumption, cost, etc, of the ECL interface electronics have been assumed to be the same as that for CMOS/SOS.

For the typical DSG data bus, it is estimated that a multiplex rate of 40 megabits per second would be required in the ECL concept, versus 18 megabits per second for the CMOS/SOS. This higher data rate would require the LED rise-time to be reduced from 20 to about 10 nanoseconds. Since the LED used in the DSG baseline does not inherently have this capability, a speedup network would be required.

Receiver sensitivity would drop 4 db in going to the higher data rate. The star coupler design concept cannot absorb this additional loss. The daisy chain design concept can absorb 4 db loss by raising the LED output from 2 milliwatts (3 dbm) to 5 milliwatts (7 dbm). The minimum link margin for this concept would then be unchanged.

Table 44 shows a comparison of the physical characteristics of the CMOS/SOS and ECL DSG daisy chain (new design) fiber optics concept.

TABLE 44. DSG NEW DESIGN; DAISY CHAIN; COMPARISON OF PHYSICAL CHARACTERISTICS FOR CMOS/SOS AND ECL TECHNOLOGIES

	CMOS/SOS	ECL
Fiber cable segments (quantity)	400	158
Fiber cable length (feet)	6,900	2,590
Bulkhead connectors (quantity)	14.5	5.7
LRU connectors (quantity)	58	58
Fiber cable weight (pounds)	48.3	18.3
Connector weight (pounds)	11.3	9
Total system weight (pounds)	62.5	29.2

These data were input to the DTLCC model along with the cost factors used in the baseline LCC evaluations (Section III). The comparative results are displayed in Table 45. The high-risk 40 mb/sec ECL concept offers a cost savings of $6.4 million over that of the lower risk 18 mb/sec CMOS/SOS concept.

TABLE 45. DSG LCC COMPARISON (DAISY CHAIN)

(All costs in Millions of 1977 Dollars)

	Wire	CMOS	ECL
RDT&E	0.0	5.1	5.1
ACQ	53.5	9.2	4.3
O&S	63.2	2.4	0.9
LCC	116.7	16.7	10.3

Alternate Super-MUX Configuration

An alternate configuration for the Super-MUX star coupler subsystem has been conceived which employs a 37-fiber cable instead of the 19-fiber cable employed in the basic configuration. The alternate concept replaces the Y-coupler in the basic concept with a cable bifurcation similar to that employed by Spectronics in their 10 mb/sec fiber optics demonstration bus. The Y-coupler is employed in the basic configuration, rather than the bifurcation, basically because (1) the use of a Y-coupler allows the data link to be made with a 19-fiber cable, rather than the more expensive and heavier 37-fiber cable and, (2) the Y-cable concept was preferred from installation

and manufacturing points of view. The Y-coupler concept makes use of standard termination techniques, whereas bifurcation would be a new and complex manufacturing process.

A comparison of the basic configuration and the alternate is shown in Table 46. The alternate shows improvement in the projected link margin.

An LCC evaluation for this design concept yielded a total LCC of 1,118.5 million, as shown herein. This represents a cost saving of only $700,000 over the baseline 19-fiber Super-MUX star coupler configuration.

(1977 $ Millions)

Cost Element	Wire	19 fibers	37 fibers
RDT&E		28.9	28.9
ACQ	1,102.7	839.2	838.6
O&S	201.1	251.1	251.0
LCC	1,303.8	1,119.2	1,118.5

FIBER OPTICS IN ADVANCED COMPOSITE AIRCRAFT STRUCTURES

Near-term application of composite materials is predicted to be primarily as covers for wing and empennage structures as well as specific secondary structural components of the fuselage. For the B-1, the difference in the EMP level offered by composites and that offered by the present skin of the B-1 is about 40-50 db. The present wire/shielding/conduit design in the wing and empennage areas are, however, overdesigned and can handle these additional levels. The "overdesign" was prompted by an economic decision to require one level of EMP protection for all circuits in the entire aircraft rather than tailoring the protection to the specific aircraft area. The result is that all areas are designed to the worst case, resulting in "overdesign" in several areas. Thus, the results obtained in the FOCAP study would be unaffected by the employment of composites on the B-1.

For other aircraft, the employment of composites may require the addition of shielding to compensate for the loss of protection of the skin. The use of aluminum conduit or single overbraid would supply about the same level of protection as the skin. This additional weight impact would depend upon the number and length of wire cables that could be replaced by fiber cables. On the B-1 aircraft, only a small percentage of wires that were candidates for fiber cables were located in the wing and empennage areas.

TABLE 46. BASIC/ALTERNATE SUPER-MUX CONFIGURATIONS COMPARISON

Characteristics	Basic	Alternate
Fiber cable used		
No. of fibers	19	37
Wt/1,000 ft (lb)	7	9
Total required (ft)	830	830
No. of segments	198	198
Total weight (lb)	5.8	7.5
No. of bifurcations	-	62
Cost ($/ft)	2.00	4.00*
Y-couplers employed (No.)	62	-
Y-coupler weight (lb)	3.1	-
Star couplers	8	8
Connectors	55	55
LED output (milliwatt)	5	2
Minimum link margin (db)	2	9
Total subsystem weight (lb)	1114.8	1113.4

*Unit cost for 37-fiber cables assumed to be twice that of 19-fiber cables.

COST DRIVERS IDENTIFICATION

Those fiber optic subsystems which offer potential LCC savings were examined in detail to create a prioritized list of cost drivers for fiber optics application. The new design DSG, EMUX, and Super-MUX configurations were selected for this exercise. Figure 43 illustrates the major contributors to LCC for these three subsystems. RDT&E cost for Super-MUX is included under the category "Other."

Examination of these results provides the following:

1. The major cost drivers are similar for the DSG and EMUX. Aside from nonrecurring costs (RDT&E), the predominant cost items are associated with procurement and installation of the fiber cables. Thus, for a given configuration with associated segment count and total footage of cable, the unit procurement cost and the man-hours required to prepare and install cable segments are major cost parameters. The subsystem weight, which directly affects fuel and tanker support costs, is also a significant item.

2. The Super-MUX configuration is dominated by the procurement cost and reliability of new computers.

Table 47 provides a further breakdown of the costs associated with the fiber optic DSG, along with a comparison to those of the wire DSG configuration. The data indicate that cable segment count reduction and subsystem weight reduction are the two most important cost drivers in LCC savings. Cable maintenance, cable preparation and installation, and cable procurement are all affected by the segment count, and the weight savings is translated into fuel and tanker support for the fixed size B-1.

When the B-1 results are extrapolated for a rubber aircraft, the subsystem weight reductions become the predominant cost parameter for LCC savings. For the DSG weight decrease of 380 pounds per aircraft, over 50 percent of the total projected LCC savings is attributable to the reduction in weight.

The results of both the sensitivity analyses and the cost trade-offs also identified additional cost drivers. The adaptation cost to modify an electronic LRU for electro-optical conversion affects LCC savings on the DSG at about $20,000 per dollar change to the baseline LRU cost. Data rate, as translated into additional wire or fiber optic segments, has also been shown to be a significant cost driver. The impact of data rates on subsystem weight is also very important when considered for future aircraft systems where the weight savings cascade throughout the total air vehicle.

Other parameters displaying a substantial influence over the LCC savings include the relative price of wire and fiber optic cable and the failure rate

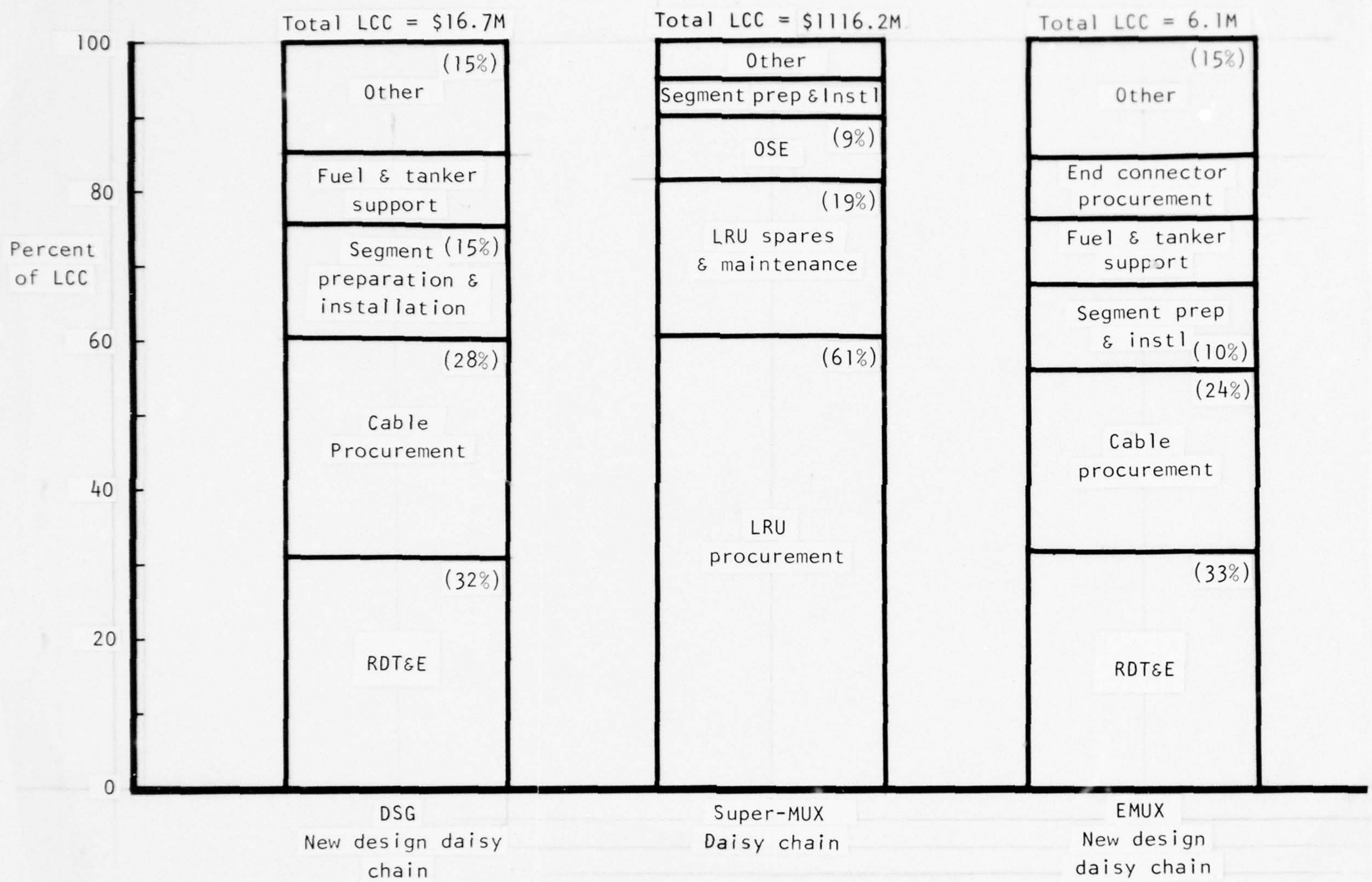


Figure 43. Cost drivers for candidate fiber optic subsystems.

TABLE 47. DSG LCC CONTRIBUTIONS - FY 1977 $ MILLIONS

(DAISY CHAIN, NEW DESIGN)

Cost category	Wire	Wire (%)	FO	FO (%)	Savings*
Segment maintenance	49.4	42	0.4	2	49.0
Segment preparation and installation	36.3	31	2.7	16	33.6
Fuel and tanker support	11.0	10	1.5	9	9.5
Cable procurement	10.8	9	4.8	29	6.0
Initial and recurring OSE	4.6	4	.8	5	3.8
End connector procurement	2.4	2	.7	4	1.7
Bulkhead connector procurement	1.2	1	.2	1	1.0
Conduit procurement	.7	1	.0	0	.7
Other	.2	0	.0	0	.2
Sustaining engineering and support	0	0	.5	3	-.5
RDT&E	0	0	5.1	31	-5.1
Total	116.7	100	16.7	100	100.0

*Minus signs indicate added costs rather than savings

of wire cable segments. Of lesser importance to the LCC savings with fiber optic subsystems, at least within the reasonable range of variation, are segment preparation and installation man-hours and segment repair times. The procurement cost of the conduit and overbraid used for EMI/EMP protection in wire subsystems is not a major cost driver.

Section VI

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The following conclusions have been reached as a result of the study:

1. The technology of fiber optics data transfer systems can support the use of fiber optics in a large aircraft like the B-1. The basic components of the fiber optics data links (fibers, connectors, terminations, light-emitting diodes (LED's) and photodetectors) are available and can be obtained in production quantities. Interface adaptation units are not available but can be developed using existing technology. Integration of fiber optics data transfer systems and testing to military specifications is yet to be accomplished.

2. Implementation of fiber optics in large aircraft such as the B-1 can result in substantial weight and life cycle cost (LCC) reduction Significant benefits occur primarily when high data rate capability is required or can be implemented through multiplexing techniques. For future military aircraft with data rates in excess of 40 mb/sec, the LCC reduction can be significantly larger than that projected for the B-1 (Figure 41).

3. The potential LCC savings of fiber optics is mainly due to substantial reductions in cable segment count and the associated weight decrease. These savings are realized in both aircraft acquisition cost (manufacturing labor and material) and operations and support costs.

4. The LCC payoff is largest during the conceptual design stages when the cascading effects of weight reduction can be realized. The weight reduction under these circumstances can contribute to a potential LCC savings of several hundred million dollars.

   When the design has matured beyond the conceptual stage and aircraft size is fixed, smaller but significant LCC reductions can be achieved if existing wire LRU's are converted to fiber optics at a production change point by replacing the wire input/output sections with fiber optics input/output sections.

RECOMMENDATIONS

As a result of this study, it is recommended that fiber optics data transfer systems be considered for all future military aircraft, especially when data rates in excess of 2-3 mb/sec are required. To minimize the technological risk, the following is encouraged:

1. More environmental testing of components and systems. Temperature and aging effects of LED's should be tested and better documented. More vibration and strength tests on cables should be performed, defining optimal use of strength members, and considering termination and splice points. Nuclear effects on components should be more fully explored, so that both transient and permanent effects on system performance can be confidently predicted.

2. Advancement of manufacturing technology is required in two areas to reduce cost and risk.

    a. Large variances in LED output within a single lot which are currently being experienced should be eliminated. This will lead to more rigorous performance predictability for the designer and larger yield factors for the manufacturer.

    b. Improved and standardized cable termination techniques should be developed.

3. Development of military standards for fiber optics components and systems should be pursued.

4. Because of the synergistic effects of multiplexing and fiber optics, an LSI package integrating high-speed multiplexing (above 50 mb/sec) and fiber optics should be developed.

5. A fiber optics data link meeting sophisticated data transfer requirements for aircraft applications should be built and flight tested to demonstrate technology under dynamic conditions.

Appendix A

FIBER OPTICS COMPONENTS DATA BANK

A fiber optics components data bank was compiled at Rockwell in support of an IR&D study of the feasibility of implementing fiber optics into the B-1 defensive subsystem group (DSG).[a] This data bank has been continuously updated as more information has become available. Tables A-1 through A-5 summarize the characteristics of fiber optic cables, connectors, couplers, LED's, and photodiodes.

In the course of gathering information for the data bank, many contacts have been established with government agencies, suppliers of fiber optics components and systems, and research and development companies. The agencies, suppliers, etc. are listed in Table A-6 along with addresses, persons contacted, and telephone numbers. All have been extremely helpful and informative, supplying data sheets, reports, and information about fiber optics data transmission components and systems.

---

[a]NA-76-305, "Potential Application of Fiber Optics Data Transfer to B-1 DSG," Rockwell International, Los Angeles Aircraft Division, 30 September 1976.

TABLE A-1. CHARACTERISTICS OF FIBER OPTIC CABLES

Designation	Manufacturer	Type	Material		Attenuation db/km at $\lambda = \mu$	Numerical Aperture	No. of Fibers per Bundle	Outside Diameters (inches)				Jacket Type	Cable Weight (lb/ 1000 ft)	Tensile Strength (pounds)
			Core	Clad				Core	Fiber	Bundle	Jacket			
F2/EXI	American Optical	S	Glass	Glass	1000, 0.8-0.9	0.66	200					Polyolefin		
F2/R6	American Optical	S	Glass	Glass	1000, 0.8-0.9	0.56	200					Polyolefin		
A/O Med Loss	American Optical	S	Glass	Glass, double clad	400, 0.8-0.9	0.66	200					Polyolefin		
BNR 7-1-A	Bell-Northern	S	Doped silica	Doped silica	15, 0.840	0.20	Single	0.004	0.006		0.024	Plastic		
BNR 7-2-A	Bell-Northern	G	Graded doped silica	Pure silica	15, 0.840	0.22	Single	0.004	0.006		0.024	Plastic		
BNR 7-2-B	Bell-Northern	G	Graded doped silica	Pure silica	8, 0.840	0.22	Single	0.003	0.006		0.016	Plastic		
CORGUIDE 1300	Corning	S	Fused silica	Fused silica	20, 0.820	0.18	7	0.0033	0.005		0.197	Polyurethane, Kevlar strengthened	17	110
CORGUIDE 1302	Corning	G	Fused silica	Fused silica	20, 0.820	0.16	7	0.0024	0.005		0.197		17	110
B-19	Corning	S	Fused silica	Fused silica	20, 0.820	0.16	19	0.0033	0.005	0.125	0.129	PVC		
5010	Corning	S	Glass	Glass	1000, 0.9	0.63	450		0.0018		0.087	PVC		

TABLE A-1. CHARACTERISTICS OF FIBER OPTIC CABLES (CONT)

Designation	Manufac-turer	Type	Material		Attenua-tion db/km at $\lambda = \mu$	Numer-ical Aper-ture	No. of Fibers per Bundle	Outside Diameters (inches)				Jacket Type	Cable Weight (lb/ 1000 ft)	Tensile Strength (pounds)
			Core	Clad				Core	Fiber	Bundle	Jacket			
5011	Corning	S	Glass	Glass	1000, 0.9	0.63	900		0.0018		0.120	PVC		
5012	Corning	S	Glass	Glass	1000, 0.9	0.63			0.0025		0.078	PVC		
5013	Corning	[illegible]	Glass	Glass	1000, 0.9	0.63			0.0025		0.093	PVC		
1025	Corning	S	DDS	DDS	10, 0.82	0.18		0.0033						
1028	Corning	S	DDS	DDS	6, 0.82	0.18		0.0033						
1150	Corning	G	DDS	DDS	10, 0.82	0.16		0.0025						
1151	Corning	G	DDS	DDS	10, 0.82	0.16		0.0025						
1152	Corning	G	DDS	DDS	10, 0.82	0.20		0.0025						
1153	Corning	G	DDS	DDS	10, 0.82	0.20		0.0025						
1156	Corning	G	DDS	DDS	6, 0.82	0.16		0.0025						
1157	Corning	G	DDS	DDS	6, 0.82	0.16		0.0025						
1158	Corning	G	DDS	DDS	6, 0.82	0.20		0.0025						
1159	Corning	G	DDS	DDS	6, 0.82	0.20		0.0025						
CROFON	DuPont	S	Plastic	Plastic	>1000, 0.9	0.52	1 to 64		0.005 to 0.05		0.110 to to 0.150	Polyeth-ylene		
PFX-0715	DuPont	S	Plastic	Plastic	>20,000, 0.9	0.53	7	0.0139	0.0146	0.044	0.075	Polyeth-ylene		

TABLE A-1. CHARACTERISTICS OF FIBER OPTIC CABLES (CONT)

Designation	Manufacturer	Type	Material		Attenuation db/km at $\lambda = \mu$	Numerical Aperture	No. of Fibers per Bundle	Outside Diameters (inches)				Jacket Type	Cable Weight (lb/1000 ft)	Tensile Strength (pounds)
			Core	Clad				Core	Fiber	Bundle	Jacket			
PFX-S140R	DuPont	S	Plastic	Plastic	20K, 0.9	0.53	Single	0.0149	0.016		0.075	Hytrel, Kevlar		88
PFX-S120R	DuPont	S	Fused silica	Plastic	50, 0.82	0.4	Single	0.008	0.024		0.095	Hytrel, Kevlar		175
QI-1-10	F.O. Cable	S	Fused silica	Plastic	20, 0.82	0.25	Single		0.010		0.10	Hytrel	4	2
QI-7-5	F.O. Cable	S	Fused silica	Plastic	50, 0.82	0.25	7		0.005	0.015	0.10	Hytrel	5	2
QI-7-10	F.O. Cable	S	Fused silica	Plastic	40, 0.82	0.25	7		0.010	0.030	0.10	Hytrel	6.7	2
QIR-1-10	F.O. Cable	S	Fused silica	Plastic	20, 0.82	0.25	Single		0.010		0.150	Hytrel, Kevlar	4.7	50
QIR-7-5	F.O. Cable	S	Fused silica	Plastic	50, 0.82	0.25	7		0.005	0.015	0.150	Hytrel, Kevlar	5.4	50
QIR-7-10	F.O. Cable	S	Fused silica	Plastic	40, 0.82	0.25	7		0.010	0.030	0.150	Hytrel, Kevlar	7.4	50
Q2R-1-10	F.O. Cable	S	Fused silica	Plastic	20, 0.82	0.25	Single		0.010	2 x 0.010	0.2 x 0.344	Duplex,(2) Hytrel, Kevlar	10.1	100

TABLE A-1. CHARACTERISTICS OF FIBER OPTIC CABLES (CONT)

Designation	Manufacturer	Type	Material		Attenuation db/Km at $\lambda = \mu$	Numerical Aperture	No. of Fibers per Bundle	Outside Diameters (inches)				Jacket Type	Cable Weight (lb/1000 ft)	Tensile Strength (pounds)
			Core	Clad				Core	Fiber	Bundle	Jacket			
Q2R-7-5	F.O. Cable	S	Fused silica	Plastic	50, 0.82	0.25	7		0.005	2 - 0.015	0.2 x 0.344	Duplex Hytrel, Kevlar	12.4	100
Q2R-7-10	F.O. Cable	S	Fused silica	Plastic	40, 0.82	0.25	7		0.010	2 - 0.030	0.2 x 0.344	Duplex Hytrel, Kevlar	15.8	100
K1/K	Galileo	S	Glass	Glass	1200, 0.8-0.9	0.66	129, 268, 290				0.030	PVC		
K2/K	Galileo	S	Glass	Glass	650, 0.8-0.9	0.66	129, 268, 290		0.0025		0.043	PVC		
Galite 1000	Galileo	S	Glass	Glass	650, 0.8-0.9	0.66	212	0.0025	0.0027	0.045	0.092	PVC, TEFZEL	PVC = 4 TEFZEL = 5	40
Galite 2000	Galileo	S	Glass	Glass	350, 0.8-0.9	0.66	212	0.0025	0.0027	0.045	0.092	PVC, TEFZEL	PVC = 4 TEFZEL = 5	40
Galite 3000	Galileo	S	Glass	Glass	100, 0.8-0.9	0.48	1,7	0.0035	0.0043	7 - 0.0130	0.056	PVC, TEFZEL	PVC = 1.3 TEFZEL = 1.4	2-4

TABLE A-1. CHARACTERISTICS OF FIBER OPTIC CABLES (CONT)

Designation	Manufacturer	Type	Material: Core	Material: Clad	Attenuation db/km at $\lambda = \mu$	Numerical Aperture	No. of Fibers per Bundle	Outside Diameters (inches): Core	Outside Diameters (inches): Fiber	Outside Diameters (inches): Bundle	Outside Diameters (inches): Jacket	Jacket Type	Cable Weight (lb/1000 ft)	Tensile Strength (pounds)
Galite 3000	Galileo	S	Glass	Glass	100, 0.8-0.9	0.48	19	0.0027	0.0033	0.017	P,T 0.056 S 0.150	P,T,S(1)	P=1.3 T=1.7 S=9.5	P 33 T 33 P 33
Galite 4000	Galileo	S	Fused silica	Plastic	40, 0.8-0.9	0.35	1, 7, 19	0.003	0.005	19 - 0.025	P,T 0.056 S 0.150	P,T,S(1)	P=1.3 T=1.7 S=9.5	P 33 T 33 S 110
Galite 5000	Galileo	S	Fused silica	Plastic	10, 0.82	0.20	1, 7	0.0024	0.0049	7 - 0.0148	P,T 0.056 S 0.150	P,T,S(1)	P=1.3 T=1.7 S=9.5	P 33 T 33 S 110
Galite 5000	Galileo	S	Fused silica	Plastic	10, 0.82	0.20	19	0.0019	0.0039	0.020	P,T 0.056 S 0.150	P,T,S(1)	P=1.3 T=1.7 S=9.5	P 33 T 33 S 110
PS-05-35	ITT/Roanoke	S	Fused silica	Plastic	40, 0.79	0.30	1,7,19	0.005	0.02		0.098	Polyurethane, Kevlar	4.3	
PS-05-20	ITT/Roanoke	S	Fused silica	Plastic	25, 0.79	0.30	1,7,19	0.005	0.02		0.098	Polyurethane, Kevlar	4.3	
PS-05-10	ITT/Roanoke	S	Fused silica	Plastic	10, 0.79	0.30	1,7,19	0.005	0.02		0.098	Polyurethane, Kevlar	4.3	
GS-02-12	ITT/Roanoke	S	Glass	Glass	20, 0.85	0.25	1,7,19	0.002	0.02		0.098	Polyurethane, Kevlar	4.3	
GS-02-8	ITT/Roanoke	S	Glass	Glass	10, 0.85	0.25	1,7,19	0.002	0.02		0.098	Polyurethane, Kevlar	4.3	
GS-02-5	ITT/Roanoke	S	Glass	Glass	6, 0.85	0.25	1,7,19	0.002	0.02		0.098	Polyurethane, Kevlar	4.3	
GG-02-12	ITT/Roanoke	G	Graded Glass		20, 0.85	0.25	1,7,19	0.002	0.02		0.098	Polyurethane, Kevlar	4.3	
GG-02-8	ITT/Roanoke	G	Graded Glass		10, 0.85	0.25	1,7,19	0.002	0.02		0.098	Polyurethane, Kevlar	4.3	
GG-02-5	ITT/Roanoke	G	Graded Glass		6, 0.85	0.25	1,7,19	0.002	0.02		0.098	Polyurethane, Kevlar	4.3	

TABLE A-1. CHARACTERISTICS OF FIBER OPTIC CABLES (CONT)

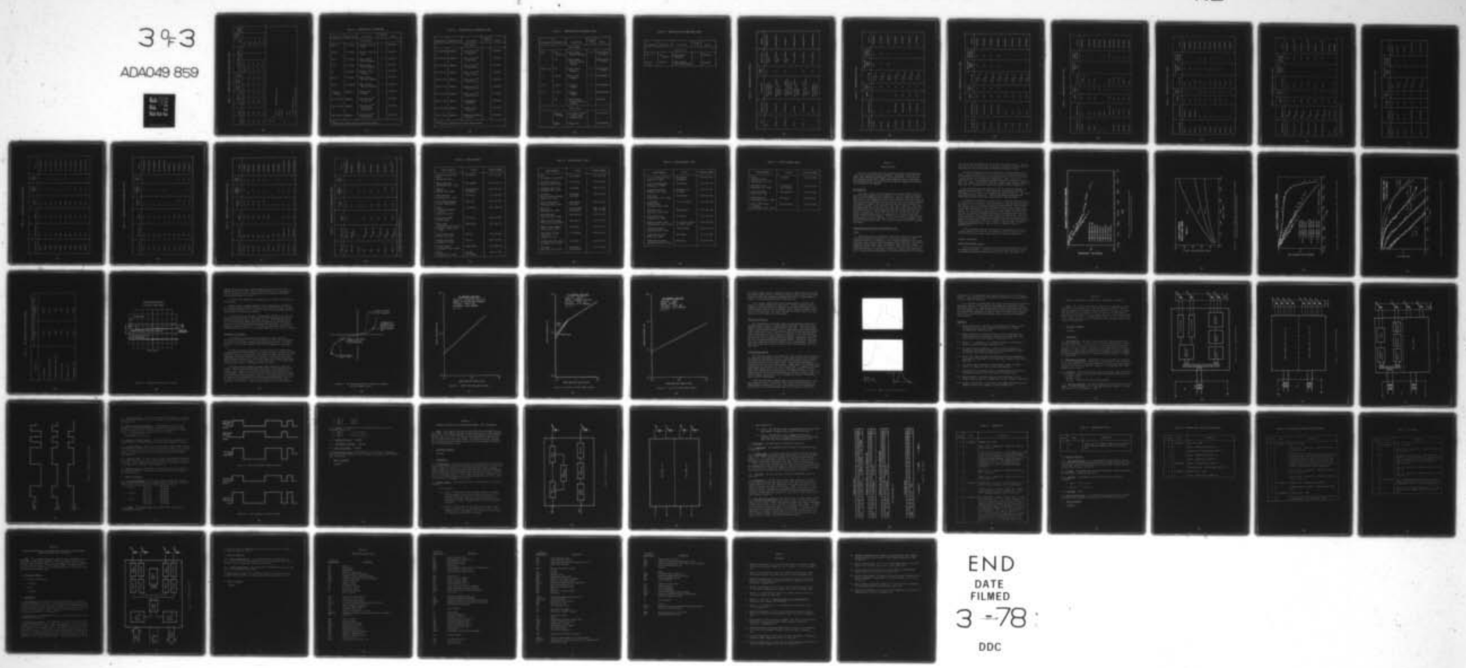
Designation	Manufac-turer	Type	Material		Attenua-tion db/km at λ = μ	Numer-ical Aper-ture	No. of Fibers per Bundle	Outside Diameters (inches)				Jacket Type	Cable Weight (lb/ 1000 ft)	Tensile Strength (pounds)
			Core	Clad				Core	Fiber	Bundle	Jacket			
	Int. F.O.	S	Plastic	Plastic	1000, 0.8	0.58	16, 19, 32, 48		0.010-0.20	0.087, 0.130		Polyeth-ylene		
1010	Poly Optics	S	Plastic	Plastic	5000, 0.9	0.51		0.0075	0.008		0.07-0.50	Polyeth-ylene		
QSF-A/B/C	Quartz Products	S	Fused silica	Fused silica	A-5, .9 B-20, .9 C-40, .9	0.17		0.008	0.024					15
Low Loss	Schott	S	Glass	Glass	250, 0.8-0.9	0.55	60					PVC		
Med Loss	Schott	S	Glass	Glass	700, 0.8-0.9	0.55	60					PVC		
RI-03	Valtec	S	Glass	Glass	400, 0.82	0.56	367	0.0024	0.00295	0.015, 0.030, 0.045	0.12	PVC, Hytrel	7	
[illegible]	Valtec	S	Fused silica	Plastic	40, 0.82	0.30	1, 7, 19	0.005	0.006	7, 0.080, 19, 0.10	19 - 0.16	PVC, Hytrel	19 - 7	200+
[illegible]	Valtec	S	Fused silica	Plastic	20, 0.82	0.30	1, 7, 19	0.0098	0.010			PVC, Hytrel		

AD-A049 859 ROCKWELL INTERNATIONAL LOS ANGELES CALIF LOS ANGELE--ETC F/G 20/6
FIBER OPTICS COST ANALYSIS PROGRAM (FOCAP).(U)
SEP 77 C C ZELON, J E CASSIDY, R G SHIPLEY F33615-76-C-1260

UNCLASSIFIED NA-77-729 AFAL-TR-77-190 NL

3 of 3

ADA049 859



END
DATE
FILMED
3-78
DDC

TABLE A-1. CHARACTERISTICS OF FIBER OPTIC CABLES (CONCL)

Designation	Manufac-turer	Type	Material		Attenua-tion db/km at $\lambda = \mu$	Numer-ical Aper-ture	No. of Fibers per Bundle	Outside Diameters (inches)				Jacket Type	Cable Weight (lb/1000 ft)	Tensile Strength (pounds)
			Core	Clad				Core	Fiber	Bundle	Jacket			
SM-10	Valtec	SM	Glass	Glass	20, 0.82			0.002-0.0006	0.004			PVC, Hytel		
MS-05	Valtex	S	Glass	Glass	10, 0.82	0.20	1, 7, 19	0.0025	0.005			PVC, Hytrel		
MS-10	Valtec	S	Glass	Glass	10, 0.82	0.20	1, 7, 19	0.005	0.010			PVC, Hytrel		
MG-05	Valtec	G	Glass	Glass	10, 0.82	0.20	1, 7, 19	0.0025	0.005			PVC, Hytrel		
MG-10	Valtec	G	Glass	Glass	10, 0.82	0.20	1, 7, 19	0.005	0.010			PVC, Hytrel		

LEGEND

Fiber Types:

S - Step index   DDS = Doped deposited silica

G - Graded index

SM - Single mode

NOTE

1. P = PVC

   T = TEFZEL

   S = Kevlar strengthened TEFZEL

2. Two cables; i.e., two channels running parallel

TABLE A-2. CHARACTERISTICS OF CONNECTORS

Designation	Manufacturer	Description	Weight (oz)	Status
		Fiber Bundles		
DPKA-34	ITT/Cannon	16-channel rack and panel	6.2	Available
DPKB-34	ITT/Cannon	16-channel rack and panel	7.75	Available
PV-14	ITT/Cannon	Single-channel PV-type bulkhead	3.0	Available
PV-18	ITT/Cannon	Single-channel PV-type bulkhead	3.0	Available
PV	ITT/Cannon	Multiple-channel bulkhead	3.2	Available
BNC-01	ITT/Cannon	Single-channel BNC-type bulkhead	1.0	Available
SMA-01	ITT/Cannon	Single-channel SMA-type bulkhead	1.0	Available
905-101/ 905-5005	Amphenol	Single-channel bulkhead	1.0	Available
905-119-5018	Amphenol	Cable plug for[a] Corning 1300		Available
905-119-5006	Amphenol	Cable plug for[a] Corning 5010, Galite 2000		Available
905-119-5005	Amphenol	Cable plug for[a] Corning 5013		Available

[a] Cable plug includes ferrule and locknut assembly.

TABLE A-2. CHARACTERISTICS OF CONNECTORS (CONT)

Designation	Manufacturer	Description	Weight (oz)	Status
		Fiber Bundles		
905-119-5004	Amphenol	Cable plug for[a] Corning 5015		Available
905-119-5007	Amphenol	Cable plug for[a] Galite 3000-7		Available
905-119-5008	Amphenol	Cable plug for[a] Galite 3000-19		Available
905-119-5011	Amphenol	Cable plug for[a] Valtec PC-05-07		Available
905-119-5012	Amphenol	Cable plug for[a] Valtec PC-05-12		Available
905-119-5013	Amphenol	Cable plug for[a] Valtec PC-05-19		Available
905-119-5014	Amphenol	Cable plug for[a] Valtec PC-05-37		Available
905-117-5000	Amphenol	Flange-mounted receptacle		Available
905-118-5000	Amphenol	Printed circuit receptacle		Available
905-119-6000	Amphenol	Multicable bulkhead connector		Available

[a]Cable plug includes ferrule and locknut assembly.

TABLE A-2. CHARACTERISTICS OF CONNECTORS (CONT)

Designation	Manufacturer	Description	Weight (oz)	Status
Fiber Bundles				
6507	NELC/ Sealectro	Single-channel pressure bulkhead	0.8	Demonstration A-7 ALOFT
	NELC	Single-channel ferrule/connector bulkhead		Demonstration A-7 ALOFT
IBM-L20-2421	IBM	Single-channel bulkhead	0.5	Demonstration A-7 ALOFT
12-3	Deutsch	Three-channel bulkhead	0.8	Developmental
20-16	Deutsch	16-channel bulkhead	2.9	Developmental
22-20	Deutsch	20-channel bulkhead	3.3	Developmental
	AMP	Single-channel ferrule/connector, bulkhead	0.5	Available
Single Fibers				
	Deutsch/ Corning	Six-channel, linear array of glass alignment rods		Experimental
	Hughes	Single fiber		Experimental

TABLE A-2. CHARACTERISTICS OF CONNECTORS (CONCL)

Designation	Manufacturer	Description	Weight (oz)	Status
Single Fibers				
BNR C-10	Bell-Northern	Single-channel bulkhead		Available
905-119-5022	Amphenol	Single channel - use with PFXS120R		Available

TABLE A-3. CHARACTERISTICS OF COUPLERS

Type	Manufacturer	Description	Weight (lb)	Application	Status
Tee	Spectronics	Splits through bifurcation of fiber bundle	0.3	Fiber bundles, AFAL	Demonstration
Radial arm	Spectronics	Eight port - couples through fiber bundles	0.3	Fiber bundles, AFAL	Demonstration
Radial arm	Spectronics	Nine port - couples through solid-glass rods, in DPKB connector shell	0.3	Fiber bundles, AFAL	Available
Star	Corning	Seven port - couples through fiber bundles		Fiber bundles	Demonstration
Star	ITT/Cannon	Nine port - built into DPKB connector shell	0.3	Fiber bundles	Demonstration
Y	Deutsch	Splits through bifurcation of fiber bundle	0.1	Fiber bundles	Demonstration

TABLE A-4. CHARACTERISTICS OF LED'S

Designation	Manufacturer	λ-peak (μ)	Rise time (ns)	Power out	Half-cone angle (deg)	Emission surface dia (mm)	Status
SL 1282	TI		15	0.6 mW at 50 mA	130	18	Available
SL 1314	TI		15	0.6 mW at 50 mA	25	18	Available
TIXL471	TI		15	1 mW at 50 mA	130	18	Available
SE 2430-1	Spectronics	0.91	20	0.75 mW at 150 mA			Available
SE 2430-2	Spectronics	0.91	20	1.0 mW at 150 mA			Available
SE 2430-3	Spectronics	0.91	20	2.0 mW at 150 mA			Available
SE 2430-4	Spectronics	0.91	20	3.0 mW at 150 mA			Available

TABLE A-4. CHARACTERISTICS OF LED'S (CONT)

Designation	Manufacturer	λ-peak (μ)	Rise time (ns)	Power out	Half-cone angle (deg)	Emission surface dia (mm)	Status
SPX 1527	Spectronics	0.91	22	1.0 mW at 50 mA	25	45	Available
SPX 1775	Spectronics	0.91	20	2.0 mW at 100 mA	15	45	Available
SPX 2231	Spectronics	0.91	15	2.0 mW at 100 mA	15	45	Available
SPX 2354	Spectronics	0.91	40	1.0 mW at 100 mA	10	45	Available
SG 1001	RCA	0.94		1.6 mW at 50 mA			Available
SG 1002	RCA	0.94		1.6 mW at 50 mA			Available
SG 1003	RCA	0.94		2.1 mW at 50 mA			Available
SG 1004	RCA	0.94		3.0 mW at 50 mA			Available

TABLE A-4. CHARACTERISTICS OF LED'S (CONT)

Designation	Manufacturer	λ-peak (μ)	Rise time (ns)	Power out	Half-cone angle (deg)	Emission surface dia (mm)	Status
SG 1009	RCA	0.94		2.2 mW at 50 mA			Available
C30119	RCA	0.85	2-3	0.5 mW			Available
C30123	RCA	0.85	5-6	1.0 mW			Available
L2	Meret		20			5	Available
L3	Meret		<12			0.5	Available
	Laser Diode	0.85	<5	1.0 mW		10 x 10	Available
HR 952F	Plessey	0.9	5	0.175 mW		30	Available
HR 953F	Plessey	0.9	5	0.350 mW		30	Available
HR 954F	Plessey	0.9	5	0.600 mW		30	Available
GAL 100	Plessey	1.06	5	5 mW		20	Available

TABLE A-4. CHARACTERISTICS OF LED'S (CONT)

Designation	Manufacturer	λ-peak (μ)	Rise time (ns)	Power out	Half-cone angle (deg)	Emission surface dia (mm)	Status
ME 2A	Monsanto	0.9	10	9 mW	43		Available
ME 4	Monsanto	0.9	1	1 mW	38		Available
ME 60	Monsanto	0.9	1	0.55 mW	35		Available
TILX35	TI	0.9	10	1.2 mW	135	60	Available
TIXL36	TI	0.9	10	1 mW	25	100	Available
TIXL06	TI	0.9	30	1.2 mW	115	8	Available
TIXL16	TI	0.93	40	400 mW	150	70	Available
TIXL27	TI	0.91	30	20 mW	135	23	Available
SLH-101	TI	0.9	15	0.1 mW		3	Available
SLH-102	TI		15	0.16 mW		3	Available

TABLE A-4. CHARACTERISTICS OF LED'S (CONT)

Designation	Manufacturer	λ-peak (μ)	Rise time (ns)	Power out	Half-cone angle (deg)	Emission surface dia (mm)	Status
BNR 40-3-10-2	Bell-Northern	0.84	4	1 mW		0.075	Available
BNR 40-3-10-3	Bell-Northern	0.84	4	1 mW		0.075	Available [a]
BNR 40-3-15-2	Bell-Northern	0.84	7	1.5 mW		0.075	Available
BNR 40-3-15-3	Bell-Northern	0.84	7	1.5 mW		0.075	Available [a]
BNR 40-3-30-2	Bell-Northern	0.84	14	3 mW		0.075	Available
BNR 40-3-30-2	Bell-Northern	0.84	14	3 mW		0.075	Available [a]
FDE	Fairchild	0.9	10		4.3		Available
FPE-100	Fairchild	0.98	50	1.2 mW	75		Available

[a]Single fiber integral with LED

TABLE A-4. CHARACTERISTICS OF LED'S (CONCL)

Designation	Manufacturer	λ-peak (μ)	Rise time (ns)	Power out	Half-cone angle (deg)	Emission surface dia (mm)	Status
FPE-104	Fairchild	0.88	10	10 mW	4.3		Available
Series 5	Int. A-V	0.88	35	5 mW at 90 mA	7	1.0	Available
Series 6	Int. A-V	0.88	35	10 mW at 200 mA	7	1.0	Available
Type 801-E	ITT/ROANOKE	0.84	7-10	0.4 mW at 100 mA			Developmental
Type 851-S	ITT/ROANOKE	0.84	20	0.75 mW at 100 mA			Developmental

TABLE A-5. CHARACTERISTICS OF PHOTODETECTORS

Designation	Manufacturer	λ-peak (μ)	Response (a/w)	Active diameter (mm)	Rise time (ns)	Status
C30807	RCA	0.9	0.62	1	3	Developmental
C30808	RCA	0.9	0.62	2.5	5	Developmental
C30813	RCA	0.9	0.62	2.5	40	Developmental
C30814	RCA	0.9	0.62	5	40	Developmental
C30809	RCA	0.9	0.65	8	10	Developmental
C30812	RCA	0.9	0.65	2.5	15	Developmental
C30822	RCA	0.9	0.65	5	7	Developmental
C30831	RCA	0.9	0.65	0.5	2	Developmental
C30843	RCA	0.9	0.65	2.5	3	Developmental
C30849	RCA	0.9	0.6	0.5	<1	Developmental

TABLE A-5. CHARACTERISTICS OF PHOTODETECTORS (CONT)

Designation	Manufacturer	λ-peak (μ)	Response (a/w)	Active diameter (mm)	Rise time (ns)	Status
C30850	RCA	0.9	0.6	1.0	<1	Developmental
C30851	RCA	0.9	0.6	2.5	<1	Developmental
C30852	RCA	0.9	0.6	5	<1	Developmental
C30853	RCA	0.9	0.6	8	<1	Developmental
C30854	RCA	0.9	0.6	11.4	<1	Developmental
PIN 3D	UDT	0.9	0.3		5	Available
PIN 5D	UDT	0.85	0.5	6	5	Available
PIN 6D	UDT	0.85	0.3-0.5		25	Available
PIN 10D	UDT	0.85	0.3-0.5		30	Available
UDT 450	UDT	0.85	0.3-0.5	2.5	30	Available

TABLE A-5. CHARACTERISTICS OF PHOTODETECTORS (CONT)

Designation	Manufacturer	λ-peak (μ)	Response (a/w)	Active diameter (mm)	Rise time (ns)	Status
UDT 450	UDT	0.85	0.3-0.5	2.5	30	Available
UDT 500	UDT	0.85	0.3-0.5	10	30	Available
UDT 600	UDT	0.85	0.3-0.5	2.5	30	Available
PIN 10	UDT	0.85	0.3-0.5	11	10	Available
PIN 25	UDT	0.85	0.3-0.5	24	50	Available
PIN 040A	UDT	0.907	0.4	2	1	Available
SGD 40	EG&G		0.5			Available
SGD-100A	EG&G		0.5	2.5	4	Available
SPX 5425	Spectronics	0.91	0.5	1.3	1	Developmental
SPX 5426	Spectronics	0.91	0.5	1.3	1	Developmental
SDX 1777	Spectronics	0.91	0.64	1.3	1.5	Developmental

TABLE A-5. CHARACTERISTICS OF PHOTODETECTORS (CONCL)

Designation	Manufacturer	λ-peak (μ)	Response (a/w)	Active diameter (mm)	Rise time (ns)	Status
SDX 2232	Spectronics	0.91	0.64	1.3	1	Developmental
5082-4207	Hewlett-Packard		0.5	1	<1	Available
TIXL80	TI		0.55	2.5	15	Developmental
7016	IR Industries	0.9	0.65	1.1	2	Available
7025	IR Industries	0.9	0.65	2.5	4	Available
7058	IR Industries	0.9	0.65	5.1	7	Available
BNR D-5-1	Bell-Northern	0.84	0.55	0.125	1	Available
BNR D-5-2	Bell-Northern	0.84	0.55	0.125	1	Available[a]

[a] Single fiber integral with BNR D-5-2.

TABLE A-6. OUTSIDE CONTACTS

Agency/supplier	Contact	Telephone number
Air Force Avionics Lab, WPAFB Dayton, Ohio 45433	Ken Trumble	(513) 255-4594
American Optical Southbridge, Mass. 01550	Walt Sigmund	(617) 765-9711
Amphenol Danbury, Conn. 06810	Allen Kasiewicz John Makuch	(203) 743-9272
AMP Corporation Harrisburg, Pa. 17105	Terry Bowen	(717) 564-0100
Bell-Northern Research Ottawa, Canada K1Y4H7	Barry Kirk	(613) 596-2305
Bendix Electrical Components Division Sidney, N.Y. 13838	Joel Bouvier	(607) 563-9511
The Boeing Company Seattle, Wash.	Dave Porter	(206) 655-5887
Bunker-Ramo Electronic Systems Division Westlake Village, Calif. 91359	Howard Parks	(213) 889-2211
Collins Radio Group Dallas, Tex. 75207	Bob Hoss	(214) 690-5000
Corning Glass Works Corning, N.Y. 14830	Roy Love	(607) 974-8812
Deutsch Company Los Angeles, Calif. 90009	Frank Roberts	(213) 649-1400
DuPont Wilmington, Del. 19898	Ken Kamm Ron Ferguson	(302) 774-7850

TABLE A-6. OUTSIDE CONTACTS (CONT)

Agency/supplier	Contact	Telephone number
EG&G Los Angeles, Calif. 90017	Eamon Murphy	(213) 484-8780
Fairchild Microwaves Palo Alto, Calif. 94303	Tom Courtney	(415) 493-3100
Fiberoptic Cable Corp. Framingham, Mass. 01701	Art Fiddes	(805) 642-3765
Fairchild Space and Defense Systems Syosset, N.Y. 11791	Gerald Buhl Erwin Wolf	(516) 931-4500
Galileo Corporation Sturbridge, Mass. 01518	Rod Anderson Carry Owen	(617) 347-9191
Harris ESD Melbourne, Fla. 32901	Scott Broadway Roy McDevitt	(305) 727-4000 (305) 727-4482
Hewlett-Packard Palo Alto, Calif. 94303	Hans Sorenson	(415) 493-1212
Hughes Aircraft Company Culver City, Calif. 90230	John Calvert	(213) 391-0711
Hughes Aircraft Company Irvine, Calif. 92705	Norb Moulin	(714) 549-5723
IBM, Federal Systems Division Oswego, N.Y. 13827	Les Masiowski	(607) 687-2121
International Fiber Optics San Diego, Calif. 92138	Carl Porter	(714) 565-7171
ITT Cannon Santa Ana, Calif. 90702	Ken Fenton Ron McCartney	(714) 557-4700

TABLE A-6. OUTSIDE CONTACTS (CONT)

Agency/supplier	Contact	Telephone number
ITT, EO Products Division Roanoke, Va. 24019	Bob Williams Ted Babcock	(703) 563-0371
Laser Diode Laboratory Metuchen, N.J. 08840	Tom Stockton	(201) 549-7700
Lockheed-California Burbank, Calif. 91503	Floyd McLerran M. Zaman	(213) 847-6121
Meret, Inc. Santa Monica, Calif. 90404	David Medved	(213) 828-7496
Naval Ocean Systems Center San Diego, Calif. 92705	Lt. Cdr. Tinston	(714) 225-7553
Poly-Optics Inc. Santa Ana, Calif. 92705	Michael Myers	(714) 546-2250
RCA Electro Optics Lancaster, Pa. 17604	Jim O'Brien	(717) 397-7661
Rockwell Science Center Thousand Oaks, Calif. 91360	Dr. Alfred S. Joseph Dr. Fred A. Blum	(805) 498-4545
Sandia Laboratories Livermore, Calif. 94550	Clifford Skoog	(415) 455-2556
Schott Optical Glass Duryea, Pa. 18642	Tom Johnson	(717) 457-7485
SEALECTRO Corporation Sherman Oaks, Calif. 91423	Howard Kay	(213) 990-8131

TABLE A-6. OUTSIDE CONTACTS (CONCL)

Agency/supplier	Contact	Telephone number
Singer Kearfott Division Littlefalls, N.J. 07424	Tim Rogers	(201) 256-4000
Spectronics, Inc. Richardson, Tex. 75080	Dr. Bob Baird Larry Stewart	(214) 234-4271
Texas Instruments Dallas, Tex. 75222	Gene Dierschke	(214) 238-4561
United Detector Santa Monica, Calif. 90905	Don Dooley	(213) 396-3175
Valtec, Fiber Optics Division West Boylston, Mass. 01583	Richard Cerney	(617) 835-6082

Appendix B

NUCLEAR EFFECTS

The B-1 is a strategic aircraft designed to perform its mission and to survive when exposed to nuclear explosions. The nuclear effects on fiber optics data transmission systems are of major importance. The effects of electromagnetic pulse (EMP), prompt gamma (gamma dose rate), total gamma dose, and neutron flux on fiber optics data transfer components and systems are discussed in this appendix.

EMP PROTECTION

Fiber optics cables transmit information via photons rather than electrons and are nonconductive and noninductive. They are completely immune to EMP, so the total EMP problem is considerably reduced by using fiber optics transmission. The bulkhead connectors for fiber optics cables are similar to those for electrical connectors, except that no electrical connection through the bulkhead is needed. Thus, the existing EMP protection technology for electrical connectors can be applied to fiber optics connectors. The interface adaptations (IA's) used in a fiber optics data system contain electrical circuitry, but do not require protection from EMP when the host LRU's are inside a shielded bay. If the LRU's were not in a shielded bay, the fiber optics connectors would have to be equipped with a conductive tube whose length is four times its diameter. The metal portion of the connector could be considered as a part of the tube. Therefore, existing technology can be utilized to effectively harden a fiber optics transmission system to the EMP environment.

TRANSIENT RADIATION EFFECTS ON ELECTRONICS (TREE)

FIBERS

Ionization caused by either gamma radiation or neutron flux "equivalent ionization" results in an increase in optical fiber absorption. This increased absorption is characterized by a transient maximum during a radiation pulse, and a recovery toward preexposure levels afterward. The transient absorption increase may be orders of magnitude higher than the residual permanent increase. The recovery of a plastic clad, pure fused silica fiber, taken from Reference B-1 and shown in Figure B-1, shows typical characteristics. The plot presents measurements of absorption normalized to the maximum

for several light wavelengths and various doses of gamma radiation. The data show that for a given fiber type, the recovery pattern has a similar form for different doses and for different wavelengths of transmitted light.

The fiber absorption increase is a function of the temperature of the fiber. Figure B-2 (Reference B-2) illustrates the temperature dependence of the maximum attenuation due to a given radiation dose. The rate of recovery from the maximum is also temperature dependent, as shown in Figure B-3 (Reference B-2). The temperature dependence function is unique to each fiber type. For example, the recovery curve for a similar fiber, shown in Figure B-4 (Reference B-2), demonstrates a pattern dissimilar to that of Figure B-3.

The total absorption after exposure to the B-1 nuclear environment was computed for several types of fibers using data from suppliers and from References B-1, B-2, and B-3. The results are listed in Table B-1. The fibers fall neatly into two categories: fibers having absorption greater than 1,000 db/km and those having total absorption less than 100 db/km.

In addition to absorption increase, a burst of ionizing radiation causes an optical fiber to fluoresce. The fluorescence is initiated during the burst and continues for a brief interval thereafter (approximately 2 microseconds). The intensity reduces exponentially following the pulse and is nearly zero at the end of the interval. The intensity is linear with dose rate and fiber length. At sufficiently high dose rates and fiber lengths, the light intensity can rise beyond the maximum acceptable by the photoelectronic devices; however, the total energy transmitted to them is not significant. The effect of the combination of luminescence and absorption is that the luminescence appears as a brief spike despite the absorption, and thereafter the absorption cancels the luminescence effect and is seen as a decaying function toward a permanent postexposure level. Such an effect is shown in Figure B-5 (Reference B-1).

At B-1 specification levels, the effect of fluorescence will be seen as a signal output of the same order of magnitude as the true signal or less. The duration of this spurious signal will be less than 2 microseconds.

INTERFACE ADAPTATIONS

Light Emitting Diodes (LED's)

LED's are susceptible to gamma radiation and suffer degradation at high total gamma dose levels. At 10^7 rads (Si), the quantum efficiency of LED's is reduced to 50 percent (References B-4 and B-5). Above this value, the

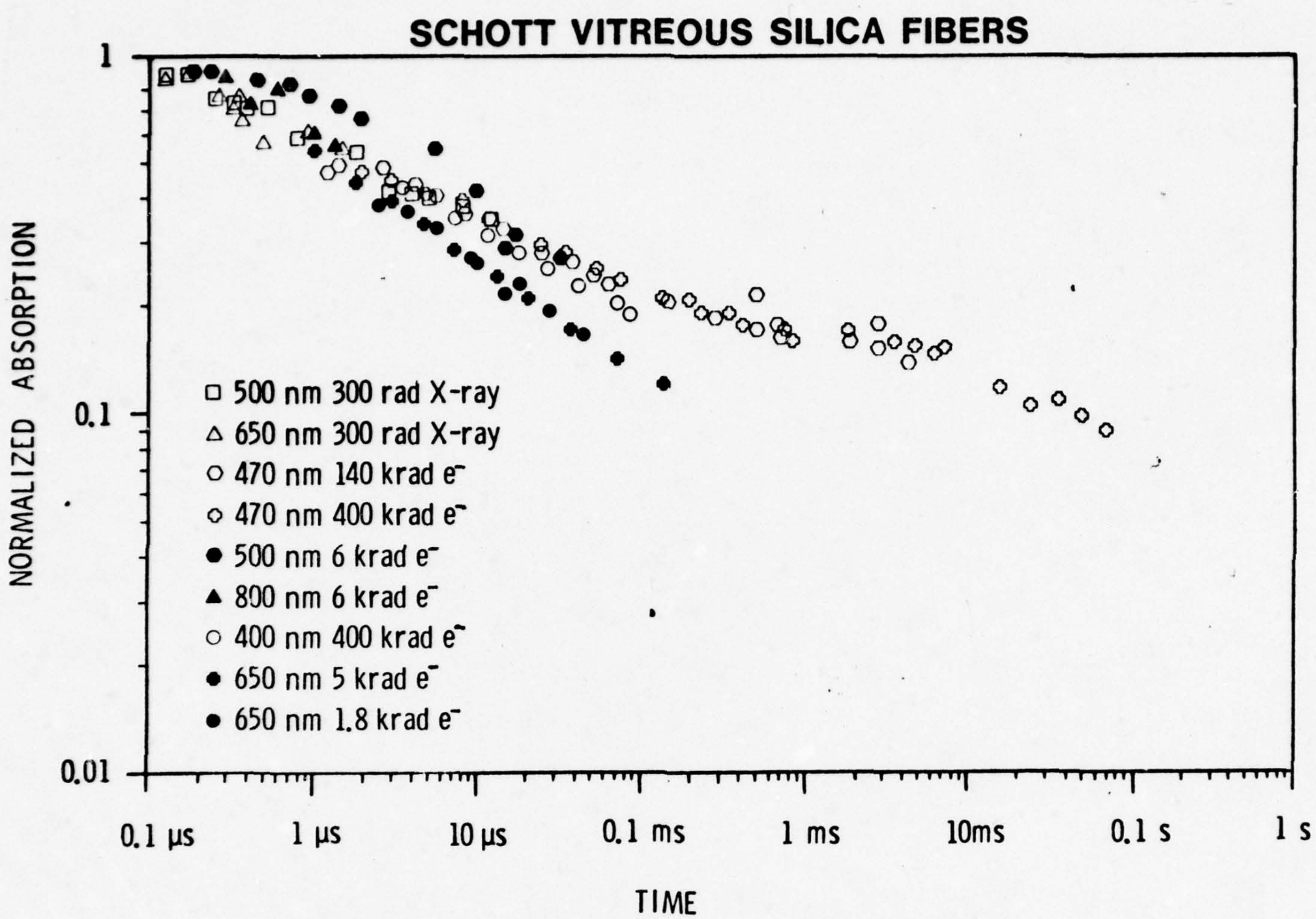


Figure B-1. Recovery from transient nuclear radiation for plastic clad, pure fused silica fiber.

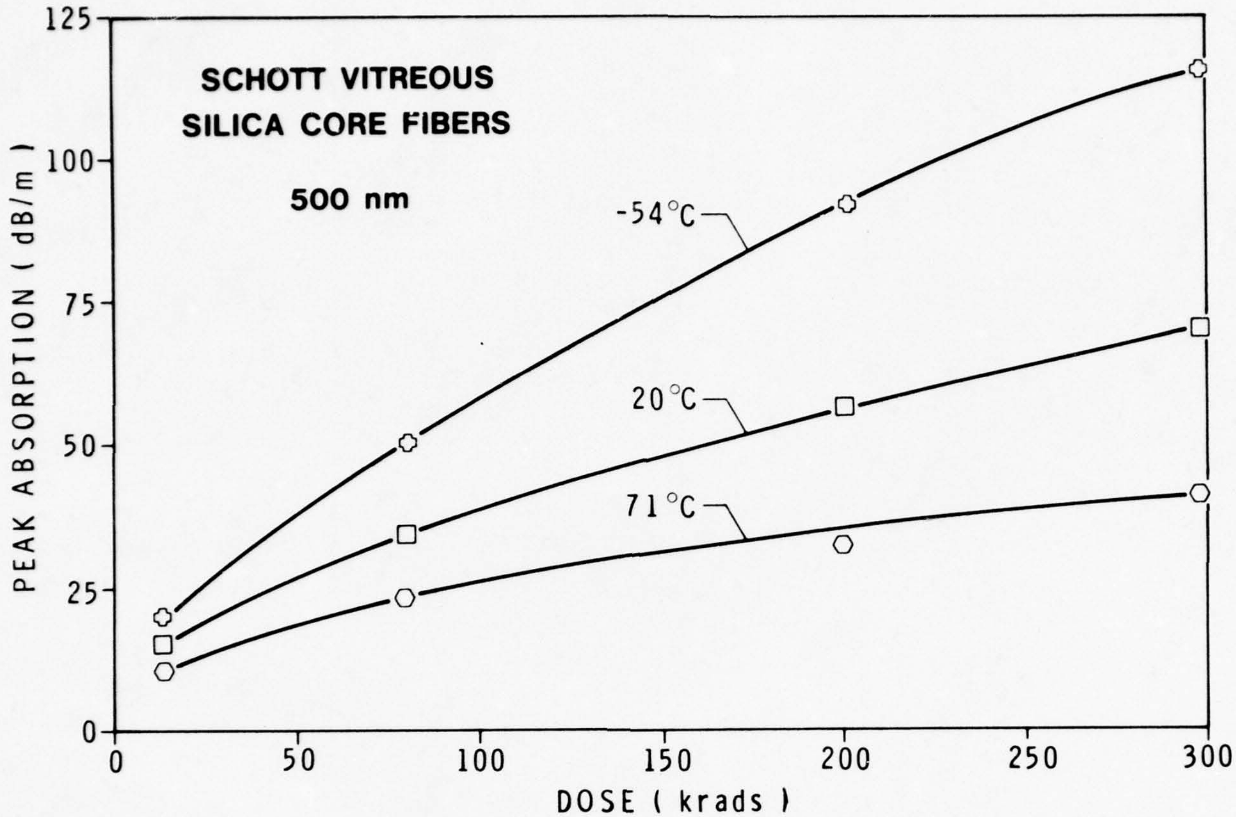


Figure B-2. The effects of temperature on the maximum value of pulse-induced, transient absorption (peak transient absorption).

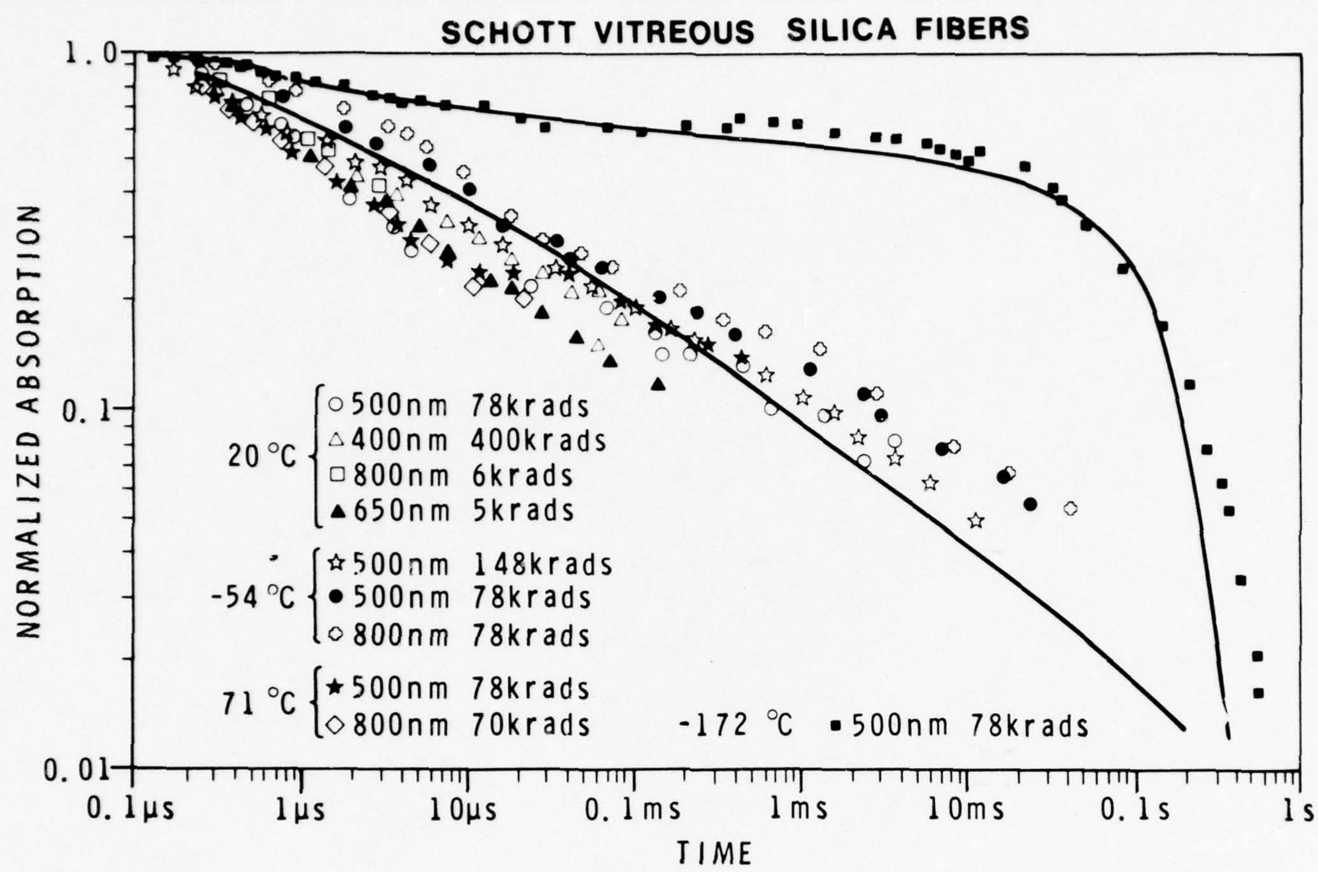


Figure B-3. Recovery of transient absorption in schott vitreous silica fibers.

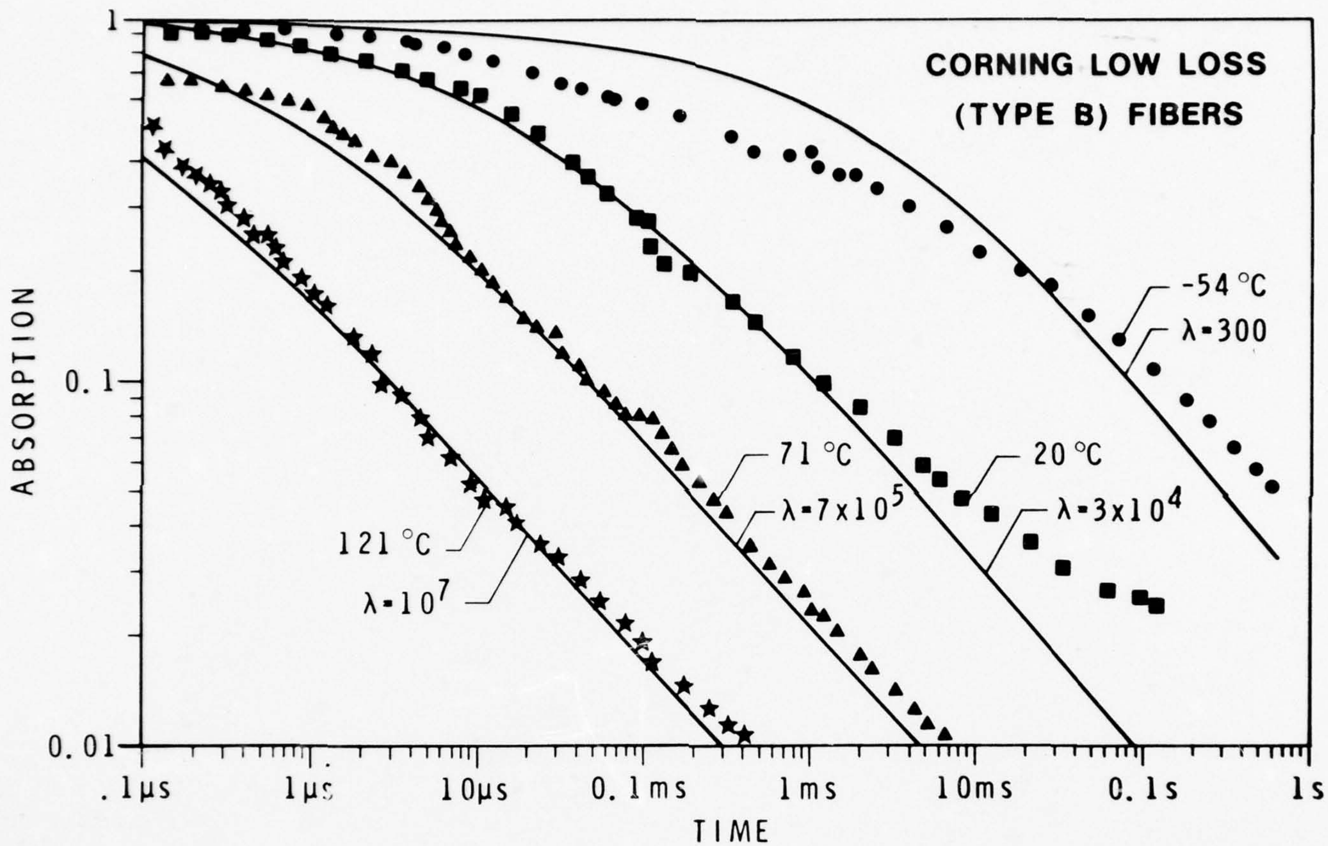


Figure B-4. Recovery of absorption versus time for corning low-loss (type B) fibers.

TABLE B-1. FIBER ABSORPTION AFTER NUCLEAR EXPOSURE

Fiber type	Absorption (0.9) after nuclear exposure (db/km)	
	Peak	Permanent
Polystyrene	>1,000	>1,000
Polymethyl methacrylate	>1,000	>1,000
Germanium-doped fused silica	< 100	< 100
Pure fused silica	< 100	< 100
Commercial glass	≥1,000	>1,000
Cerium-doped glass	>1,000	>1,000

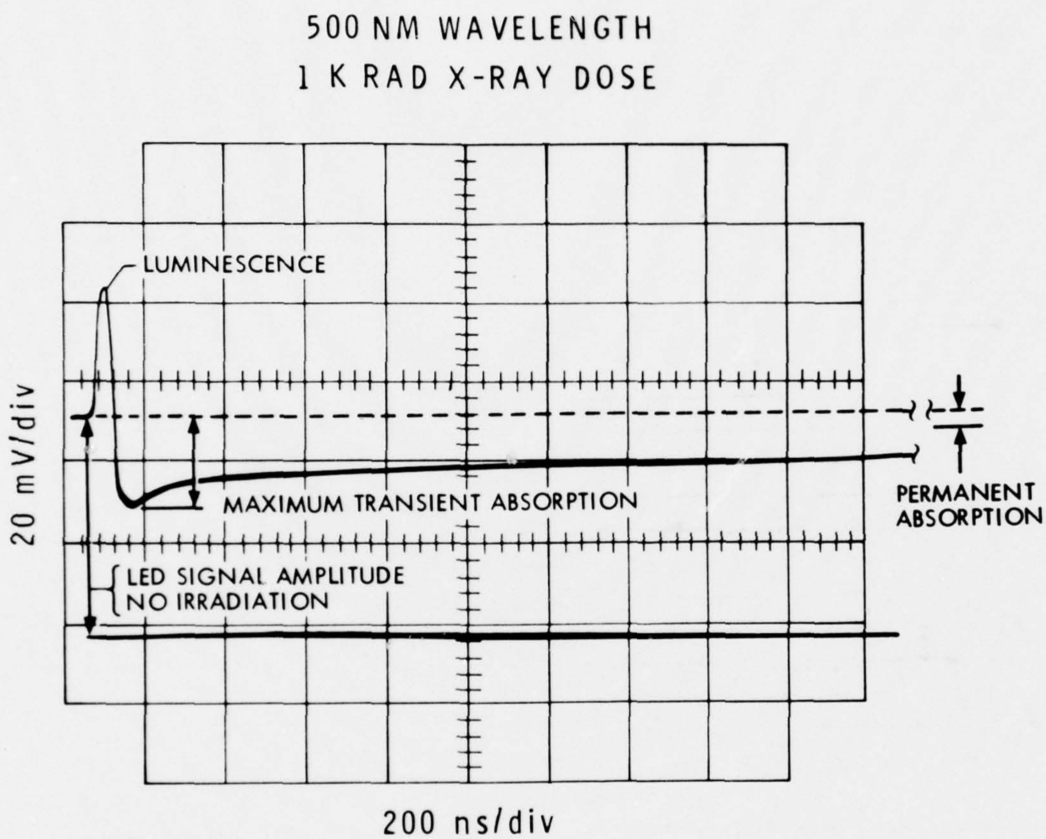


Figure B-5. Polystyrene fiber nuclear response.

quantum efficiency decreases almost exponentially and at 10^8 rads (Si), it degrades by a factor of 300. At the level of 10^8 rads (Si), the minority carrier lifetime will also be degraded, and it will suffer a seven-fold decrease (References B-4 and B-5).

At the B-1 total gamma dose requirement level, no effect is expected to occur on LED's.

Neutrons inflict permanent damage in LED's, exhibited by a reduction in the external quantum efficiency at fluence levels above 10^{13} N/cm^2. At the B-1 requirement fluence level, a reduction in the external quantum efficiency on the order of 15 percent is expected.

A transient pulse of ionization (prompt gamma) incident on the LED will produce electron-hole pairs in the region of the P-N junction, resulting in a forward current flow due to the forward biasing. If the intensity (rads (Si) is great enough, photon output will be generated for the duration of the pulse, with the LED resuming normal operation afterwards. The intensity required to generate light is 3.5 x 10^{10} rads (Si) per second for a typical LED (References B-4 and B-6). At B-1 prompt gamma levels, no effect is expected.

Photodiodes (PIN Diodes)

Total gamma dose susceptibility of photodiodes ranges from 10^4 to 10^6 rads (Si) (Reference B-1), where the effects are in the form of permanent degradation of the diodes current-voltage characteristic curve. (See Figure B-6.) No effects are expected at the B-1 total gamma dose requirement level.

The PIN diode becomes vulnerable to neutron effects at a fluence level of approximately 10^{17} N/cm^2 (References B-4 and B-7), where junction capacitance and series resistance are degraded. The quantum efficiency will generally be independent of neutron radiation since the device is operated in the fully depleted region (reverse bias), where absorption of all incident quanta takes place only in the intrinsic layer (I layer of PIN diode). At B-1 requirement neutron fluence levels, no detectable effects will occur.

PIN diodes generally respond to prompt gamma radiation by producing a forward current waveform which follows the waveform of the gamma pulse quite closely. This response is facilitated by the reverse biased operation of the photodiode. Similar devices are used to monitor gamma intensity in flash X-ray radiation testing with good reliability. Tests performed on PIN devices by Singer-Kearfott (Reference B-8) indicate induced photocurrents from 10 ma to 100 ma at a gamma dose rate of 10^6 to 10^8 rads (Si) per second. (See Figures B-7, B-8, and B-9.) These current transients are easily handled by

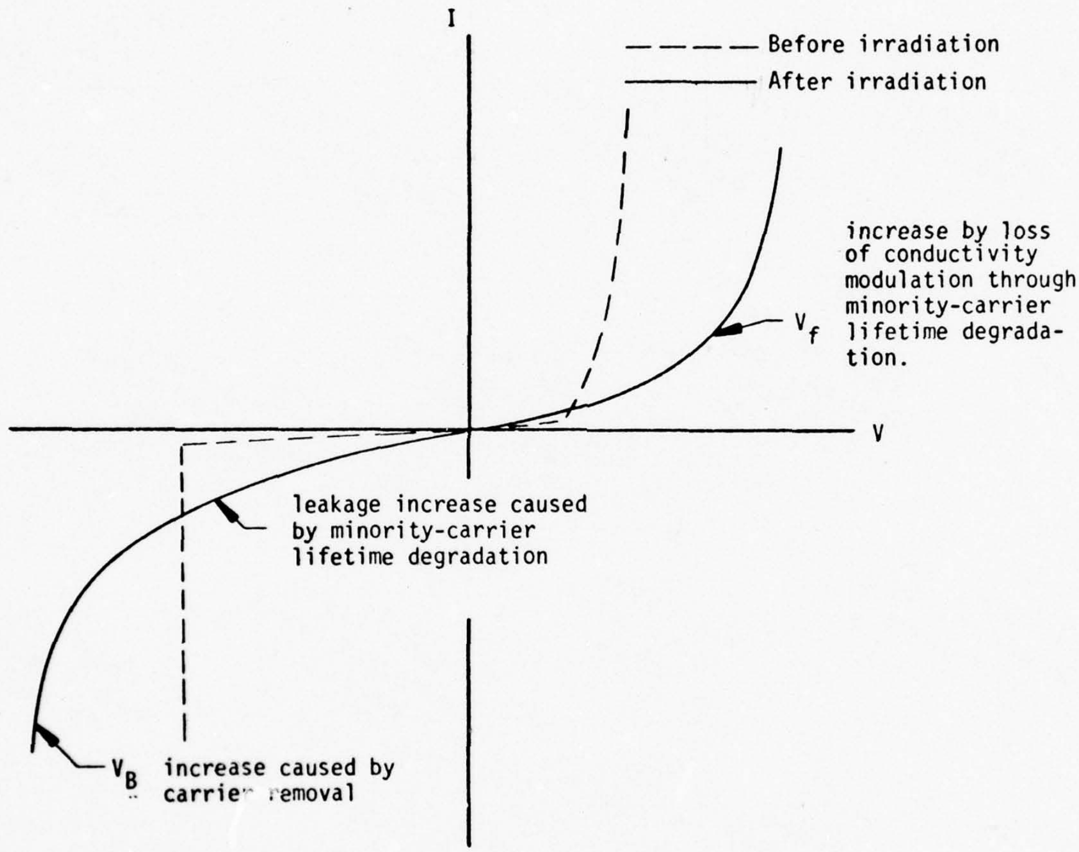


Figure B-6. PIN diode characteristic response to permanent radiation damage effects.

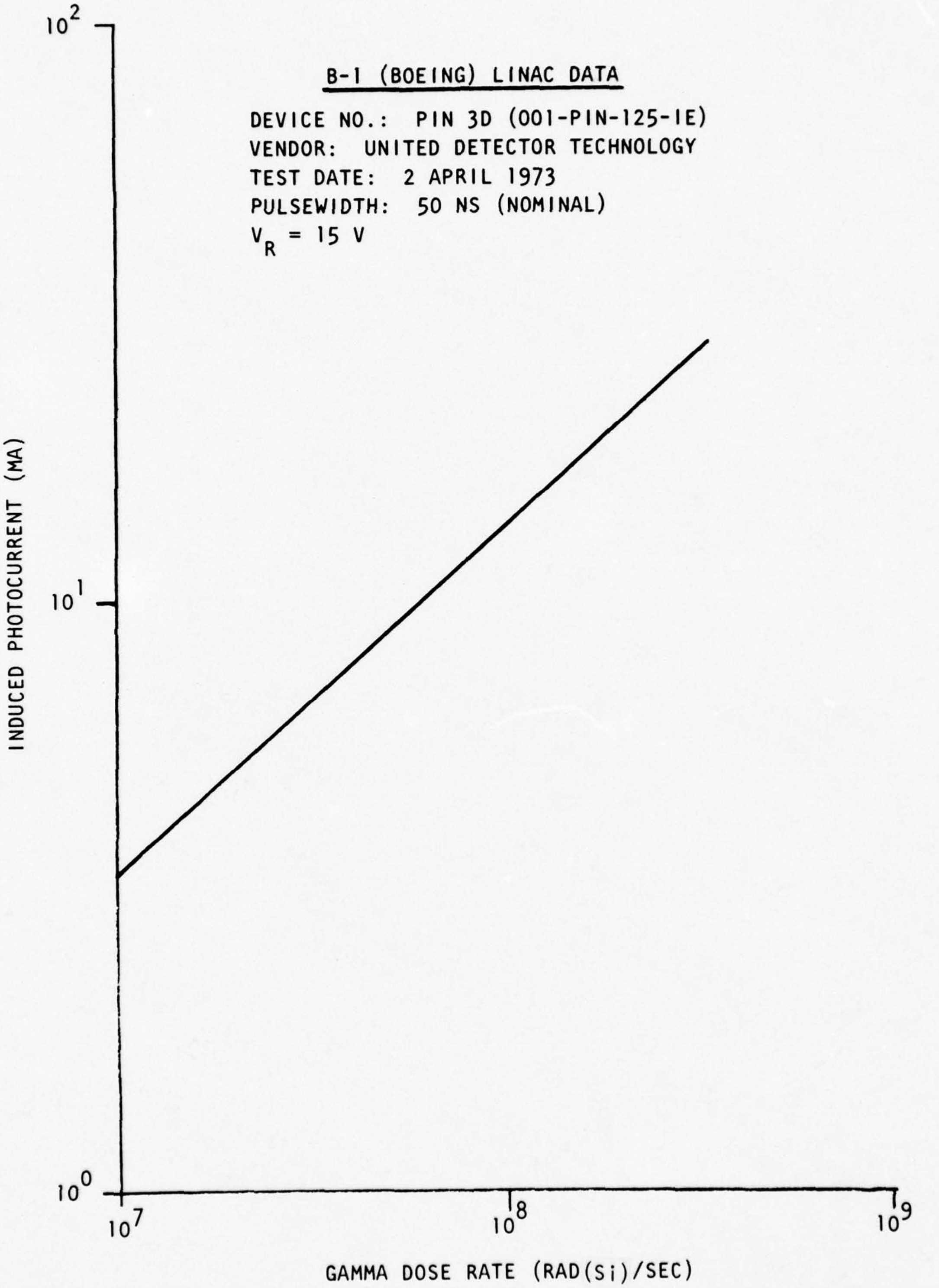


Figure B-7. UN4001 PIN diode gamma response.

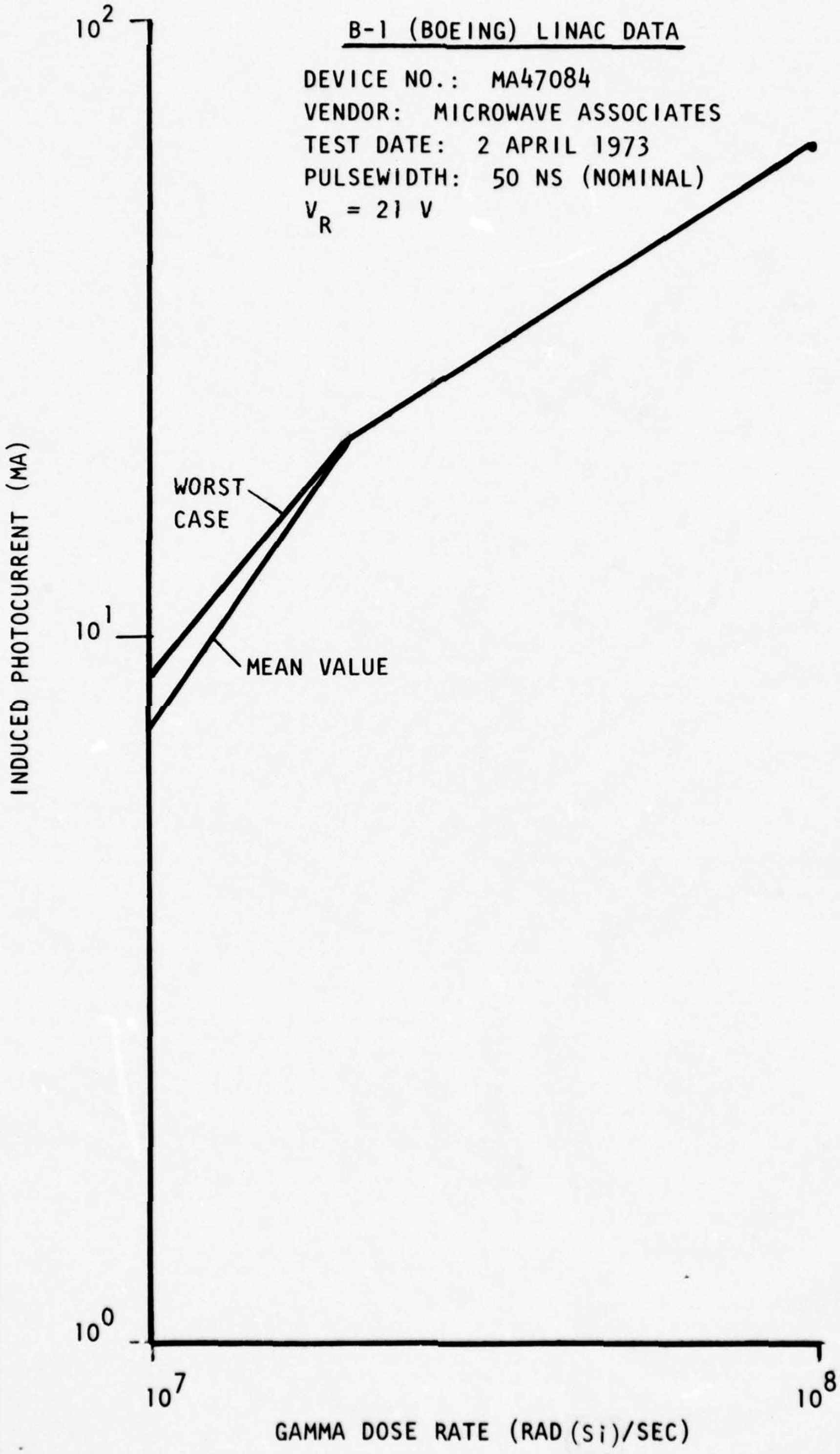


Figure B-8. MA47084 PIN diode gamma response.

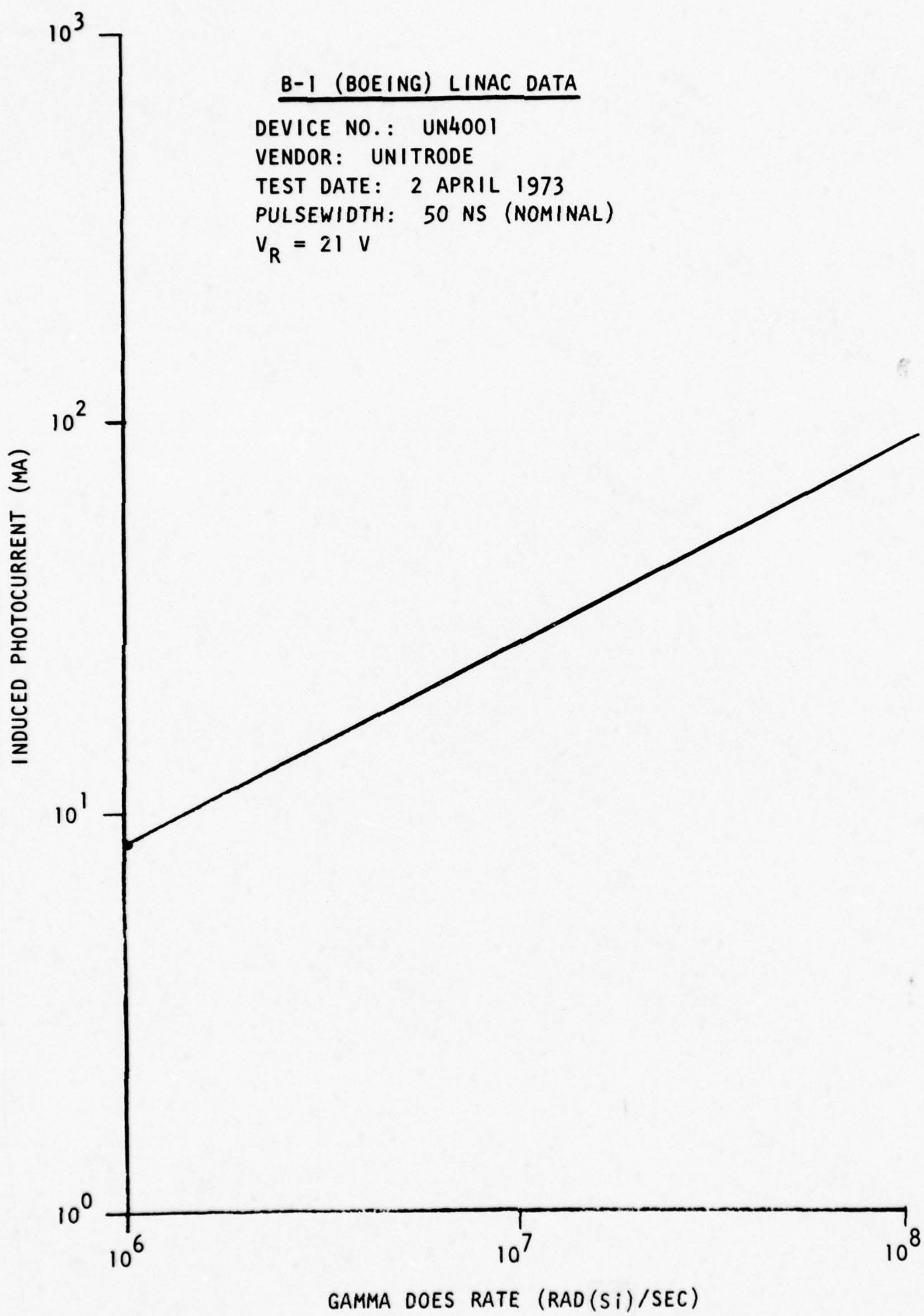


Figure B-9. PIN 3D PIN diode gamma response.

the diode structure, which is normally designed to handle high surge currents to prevent burnout, but does introduce a spurious signal into the data system. Figure B-10 shows the response of an MRD500 PIN diode to a gamma radiation pulse in a test performed by Rockwell (Reference B-9).

At B-1 levels, transient upset due to prompt gamma is expected, with recovery to normal following the gamma pulse. Various integrated circuit components, presently used in B-1 avionics, have response waveforms at their output terminal which are device dependent and do recover to pregamma state in 0 to 50 microseconds. The loss of one data bit or data frame is the only expected result of exposure to prompt gamma.

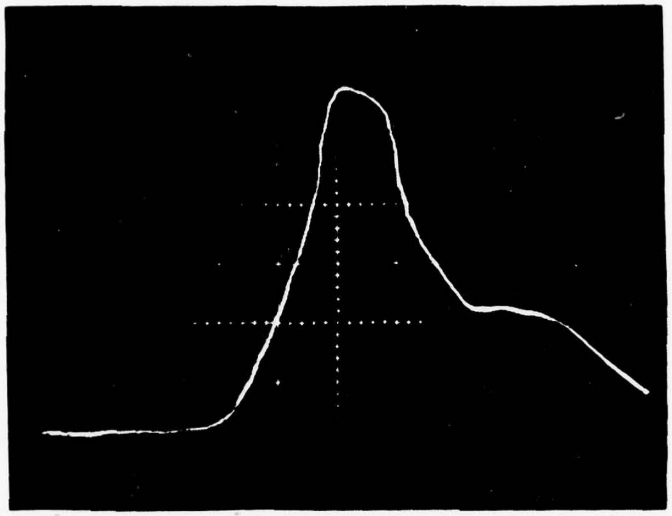
Supporting Electronics

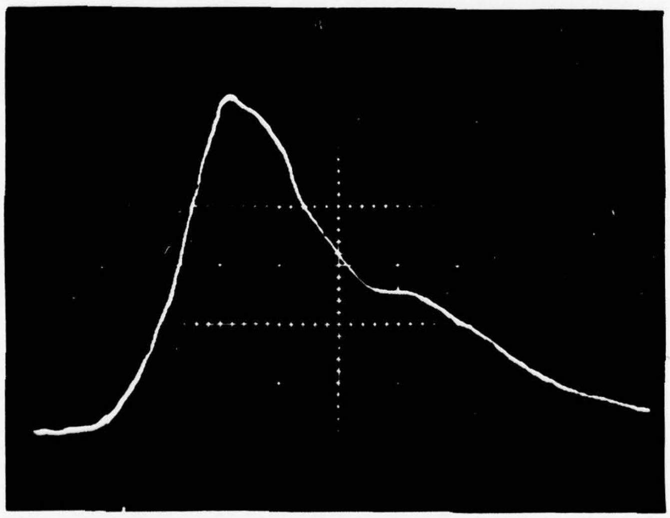
The susceptibility of the fiber optics system supporting electronics is dependent upon the types of component devices employed. These devices may include low-power Schottky, emitter-coupled logic (ECL), silicon-on-sapphire (SOS), current feedback coupling (CFC), or complementary metal oxide silicon (CMOS) integrated circuits. Each of these types of devices has been incorporated to some degree in the B-1 avionics, especially in the later designs, and has been tested in various nuclear environments. The results have shown that the newer device technology typically produces vulnerability levels of one order of magnitude higher than previous devices. The nuclear event will impact the supporting electronics primarily due to prompt gamma. Transient upset will occur, with recovery to normal at the reinitialization of a new data frame.

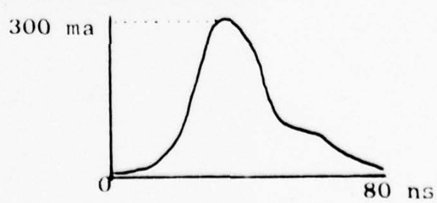
SYSTEM NUCLEAR EFFECTS

The total fiber optics data transmission system response can be predicted by considering the component effects. Prompt gamma causes spurious signals to be produced by ionization in the photodiodes and fluorescence in the fibers. The maximum duration of the primary effect is due to fiber fluorescence, estimated to last less than 2 microseconds. Prompt gamma will obliterate data transmission for a period of less than 2 microseconds. It should be noted that prompt gamma affects much of the aircraft electronics similarly, and that those LRU's sending and receiving data will be similarly affected. Thus, it would not be the fiber optics system alone which suffered transient upset. All digital computer systems on the B-1 are designed to recover from transient upset caused by prompt gamma.

Fibers and LED's have permanent effects due to the nuclear blast. LED's may be expected to have a decrease in their external quantum efficiency of approximately 15 percent (or 0.7 db). Some fibers are very susceptible to nuclear effects, but germanium-doped, fused-silica and pure, fused-silica







Scale:
Vert 5V/div.
Hor 10 ns/div.

Figure B-10. MRD500 PIN diode gamma response.

fibers have far less absorption after exposure than most other types before exposure. Their predicted total absorption of 100 db/km is easily acceptable in the B-1 data bus subsystems.

It is, therefore, concluded that fiber optics data transmission systems are expected to operate in the B-1 nuclear environment as efficiently as other electronics on the B-1. Although the analysis and the conclusions were based on a fair amount of test data, it would be desirable to expose any fiber optics data transmission components selected for the B-1 to nuclear levels required for the B-1, and to test their performance before, during, and immediately after exposure.

REFERENCES

B-1. Sandia Laboratories, "The Effects of Radiation on the Absorption and Luminescence of Fiber Optic Waveguides and Materials, " Report No. SAND74-8622, dated July 1974.

B-2. Sandia Laboratories, "Absorption Induced in Optical Waveguides by Pulsed Electrons as a Function of Temperature, Low Dose Rate, Gamma and Beta Rays, and 14 MeV Neutrons," dated October 1975.

B-3 Bryant, J. F., and Wall, J. A., "Radiation Effects on Fiber Optics," Report No. AFCRL-TR-75-0190, dated April 1975.

B-4 Air Force Avionics Laboratory, "A Survey of the Vulnerability of Contemporary Semiconductor Components to Nuclear Radiation," Report No. AFAL-TR-74-61, AD922204, dated June 1974.

B-5 Shore, Efal, "Radiation Damage and Hardening Effects on Compensated GaAs Light Emitting Diodes," IEEE Transaction on Nuclear Science NS-20, dated 1963.

B-6 Air Force Avionics Laboratory, "Optoelectronic Aspects of Avionic Systems II," Report No. AFAL-TR-75-45, dated May 1975.

B-7 Institute of Environmental Sciences, "Permanent Radiation Effects on Semiconductor Devices," 1963 Proceedings, dated April 1963.

B-8 Singer-Kearfott, "Piece-Part Gamma Dose Rate Test Report for B-1 Avionics Control Unit Part 1," Report No. Y257A071, dated 27 August 1975.

B-9 Rockwell International, B-1 Division, "TREE Component Radiation Tests," Report No. TFD-72-1257, Appendix 1, dated November 1972.

Appendix C

TECHNICAL DESCRIPTION OF ELECTRO-OPTICAL ADAPTER UNIT (RETROFIT)

1. SCOPE. This technical description establishes the requirement for the fiber optics study (FOCAP) electro-optical adapter unit (EOAU). The EOAU shall be designed to be mounted inside the host LRU to perform its function. The EOAU shall not be considered an LRU. The power to the EOAU shall be supplied by the host LRU or from an external power bus. There shall be three different types of EOAU's: a single-channel, type A (for use by CITS LRU's): a dual-channel, type B (for use by AMUX LRU's); and a unipolar-channel, type C (for use by EMUX LRU's).

2. APPLICABLE DOCUMENTS

(TBD/TBR)

3. REQUIREMENTS

3.1 Item Definition. The EOAU's shall provide the interface between the existing LRU Manchester II (Bi-ϕL) type of interface and the optical fibers. The EOAU's shall contain the Manchester II signal receiver(s), LED driver(s), necessary electronic filter(s)/receiver(s) for the photodetector signals, Manchester II signal encoder, transformer(s) and driver circuitry to output Manchester II signals back to the LRU. Block diagrams of the type A adapter, the type B adapter, and the type C adapter are shown in Figures C-1 through C-3 respectively.

3.2 Manchester II Receiver. The Manchester II receiver shall be connected to the existing Manchester II output lines of the host LRU. The function of the receiver shall be to accept the Manchester II signals and output unipolar signals for use by the LED drivers. Figure C-4 is a simplified I/O timing diagram of the receiver.

3.3 LED Driver. The LED driver shall accept the unipolar signal and convert it to a signal capable of driving a LED with the following characteristics:

Voltage: 6 volts
Current: 175 ma
Rep rate: 1 mhz (on/off cycle, 500 nsec ON/OFF)

3.3.1 Type A/B LED Driver. The type A/B LED driver shall accept the receiver output (+) signal and drive the (+) LED, and the receiver output (-) signal and drive the (-) LED (Figures C-1 and C-2).

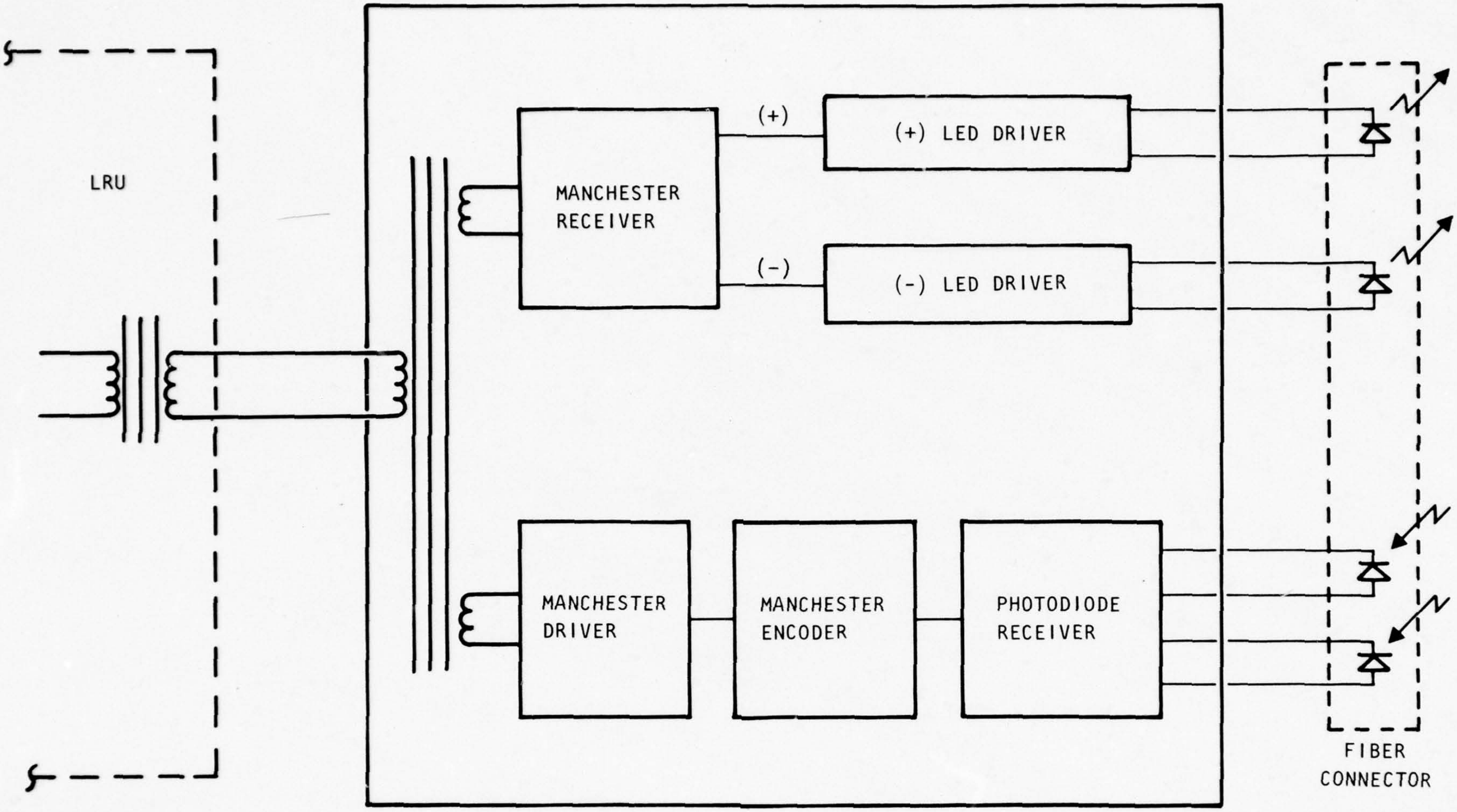


Figure C-1. Type A, single-channel EOAU.

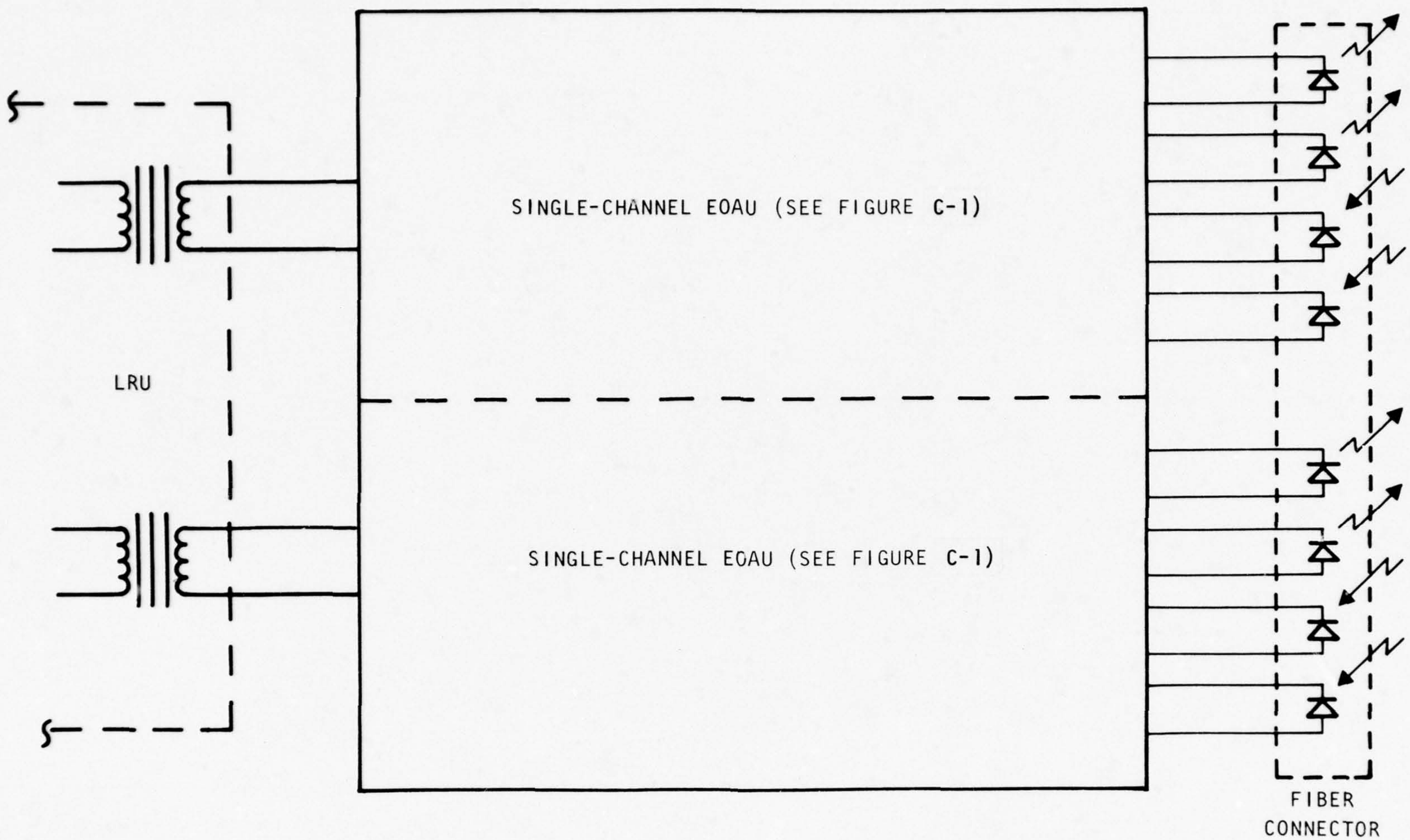


Figure C-2. Type B, dual-channel EOAU.

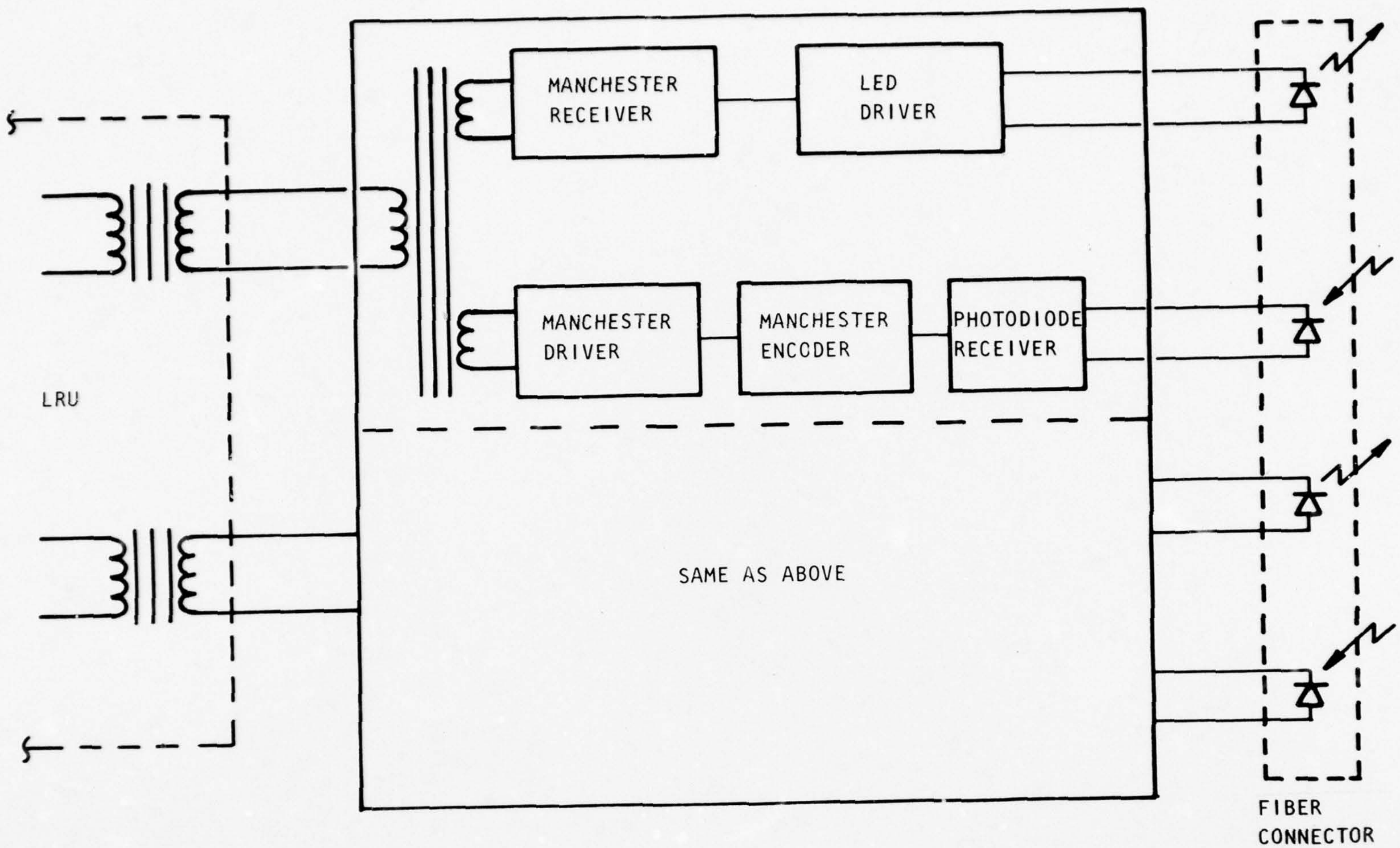


Figure C-3. Type C, unipolar EOAU.

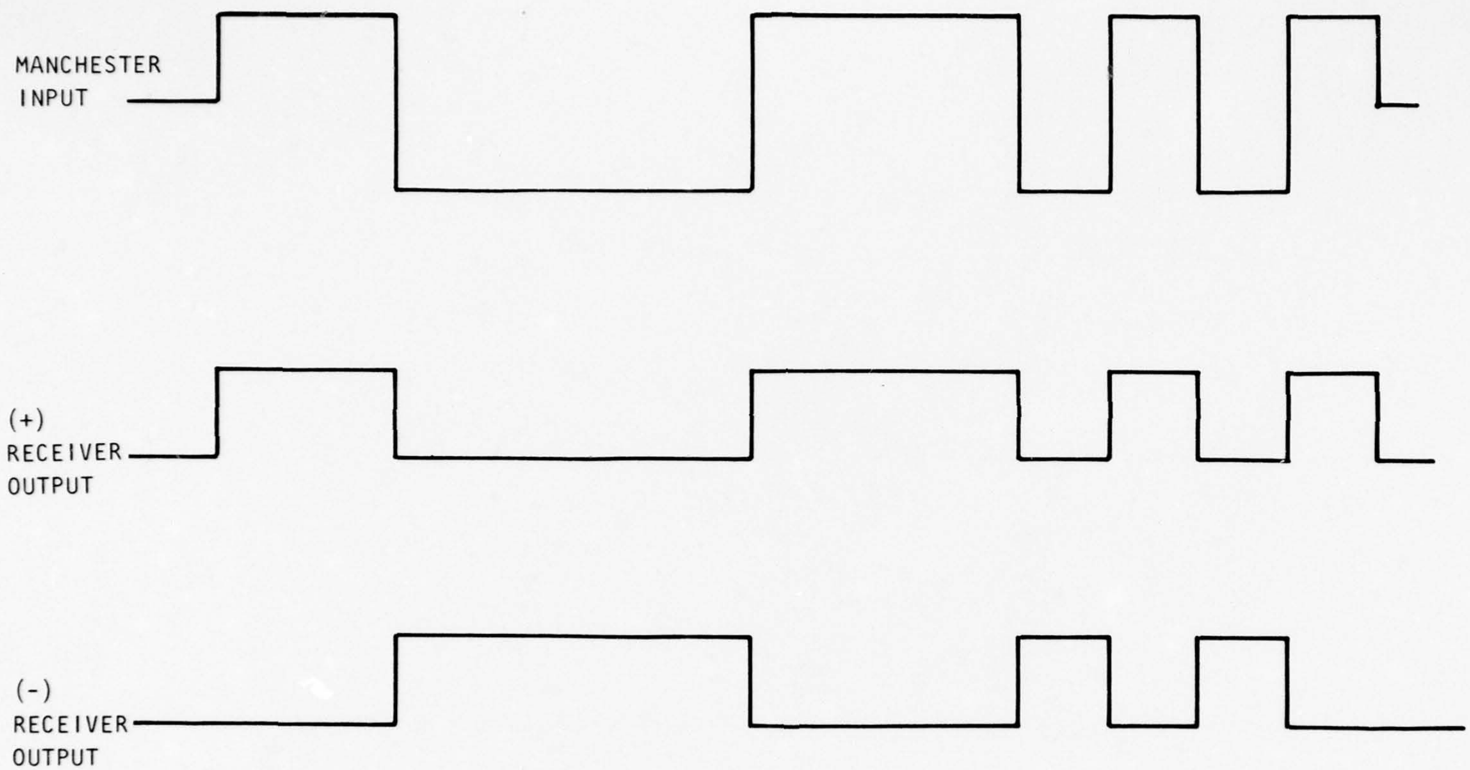


Figure C-4. Manchester receiver timing.

3.3.2 Type C LED Driver. The type C LED driver shall consist of a unipolar driver and shall accept only the receiver output (+) signal and drive the (+) LED (Figure C-3).

3.4 Photo Detector Filter/Receiver. The photodetector filter/receiver combination shall properly condition the signal received from the photodetector and convert it into a usable signal for the Manchester II signal encoder. The photodetector characteristics are as follows:

Bias voltage: 90 volts
Current range: 1.5 to 20 na

3.5 Manchester II Signal Encoder. Each EOAU shall contain a Manchester II signal encoder. The encoder shall be driven by the photodetector receiver.

3.5.1 Type A/B Encoder. The type A or type B signal encoder shall generate the Manchester II signal based on the received optical signal. The (+) signal line shall generate the positive voltage portion of the waveform and the (-) signal line shall generate the negative voltage portion of the waveform. (See Figure C-5.)

3.5.2 Type C Encoder. The type C signal encoder shall generate a Manchester type signal that is usable by the interfacing LRU. The encoder shall process the single received signal and generate both positive and negative portions of the Manchester II waveform. (See Figure C-6.)

3.6 Manchester Driver. The Manchester driver shall utilize the output of the encoder and drive the transformer to transmit the converted signals to the interfacing LRU.

3.7 Physical Properties

3.7.1 Power Considerations. The different types of EOAU shall use power supplied either by the host or by a supply external to the LRU. The EOAU's shall operate with power having the following characteristics:

a. Type A:	+5V (±5%)	180 ma max
	+15V (±5%)	60 ma max
	-15V (±5%)	60 ma max
b. Type B:	+5V (±5%)	360 ma max
	+15V (±5%)	120 ma max
	-15V (±5%)	120 ma max
c. Type C:	+5V (±5%)	260 ma max
	+15V (±5%)	60 ma max
	-15V (±5%)	60 ma max

3.7.2 Weight. The maximum weight for the EOAU's shall not exceed the following for each type:

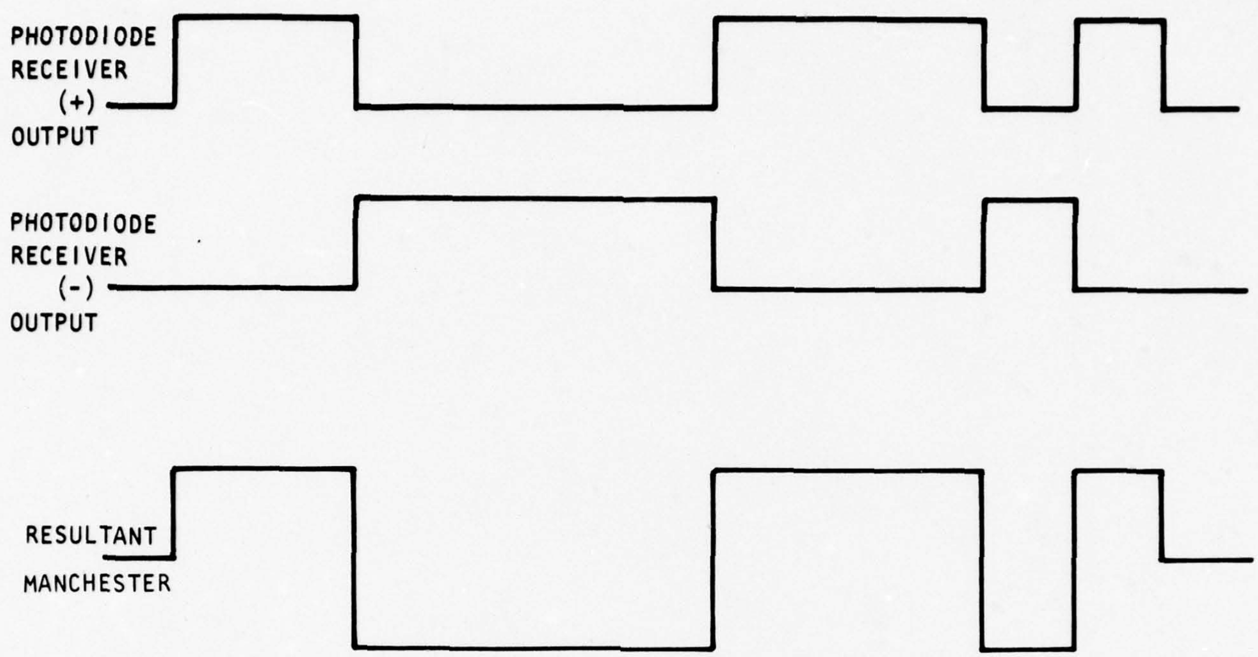


Figure C-5. Type A/B manchester encoder waveform.

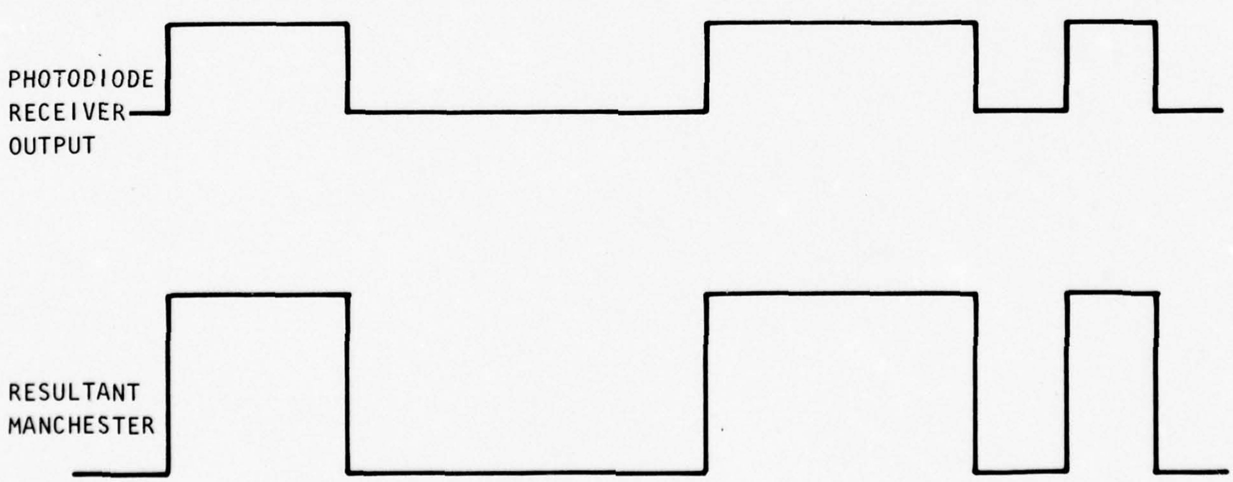


Figure C-6. Type C manchester encoder waveform.

a. Type A: 0.25 lb
b. Type B: 0.45 lb
c. Type C: 0.40 lb

3.7.3 Envelop. The maximum size for the EOAU's shall not exceed the following for each type:

a. Type A: 1 x 2 x 0.5 in. H
b. Type B: 2 x 2 x 0.5 in. H
c. Type C: 1.5 x 2 x 0.5 in. H

3.7.4 Mounting Provision. (TBD/TBR)

3.7.5 Input/Output Interface. (TBD/TBR)

3.8 Dynamic Environment. (TBD/TBR)

3.9 Microelectronic Parts. MIL-M-38510 parts shall be used. When MIL-M-38510 parts are not available, parts screening in accordance with MIL-STD-88e shall be performed.

4. QUALITY ASSURANCE

(TBD/TBR)

Appendix D

TECHNICAL DESCRIPTION OF FIBER INTERFACE MODULE (FIM) (NEW DESIGN)

1. SCOPE. This technical description establishes the requirements for the fiber optics study (FOCAP) interface circuitry identified as a fiber interface module (FIM). The FIM shall provide the interface between its host LRU and the fiber optics data bus. The FIM shall be installed inside the host LRU and be powered by the LRU's power supply. The FIM shall be used to replace the existing serial data transmission section of those equipment interfacing on the CITS and EMUX data buses.

2. APPLICABLE DOCUMENTS

(TBD/TBR)

3. REQUIREMENTS

3.1 Item Definition. The FIM shall convert a serial NRZ data stream into an optical data stream, and convert an optical data stream into a serial NRZ data stream. Appropriate sync bits are also generated and decoded to provide proper startup. The FIM also includes self-test logic, necessary LRU buffers, and electrical/optical and optical/electrical driver and receivers. The FIM shall be configured either as a dual-channel (two identical channels), type A, for use in the EMUX subsystem, or as a single-channel, type B, for use in the CITS subsystem. (See Figures D-1 and D-2.)

3.2 Message Sequence. The FIM shall receive or transmit data in the following form:

a. Data Reception:

(1) Form A. The FIM shall accept from the controller a command word and n-numbers (not to exceed 1023) of data words. The received optical data shall be converted to NRZ data for transfer to the LRU. Following the last data word received, the FIM shall generate a response word for status check by the controller.

(2) Form B. The form shall be identical to form A above except for the response word. If the FIM does not receive a valid command word or if the number of data words exceed 1023 words, the response word shall not be generated.

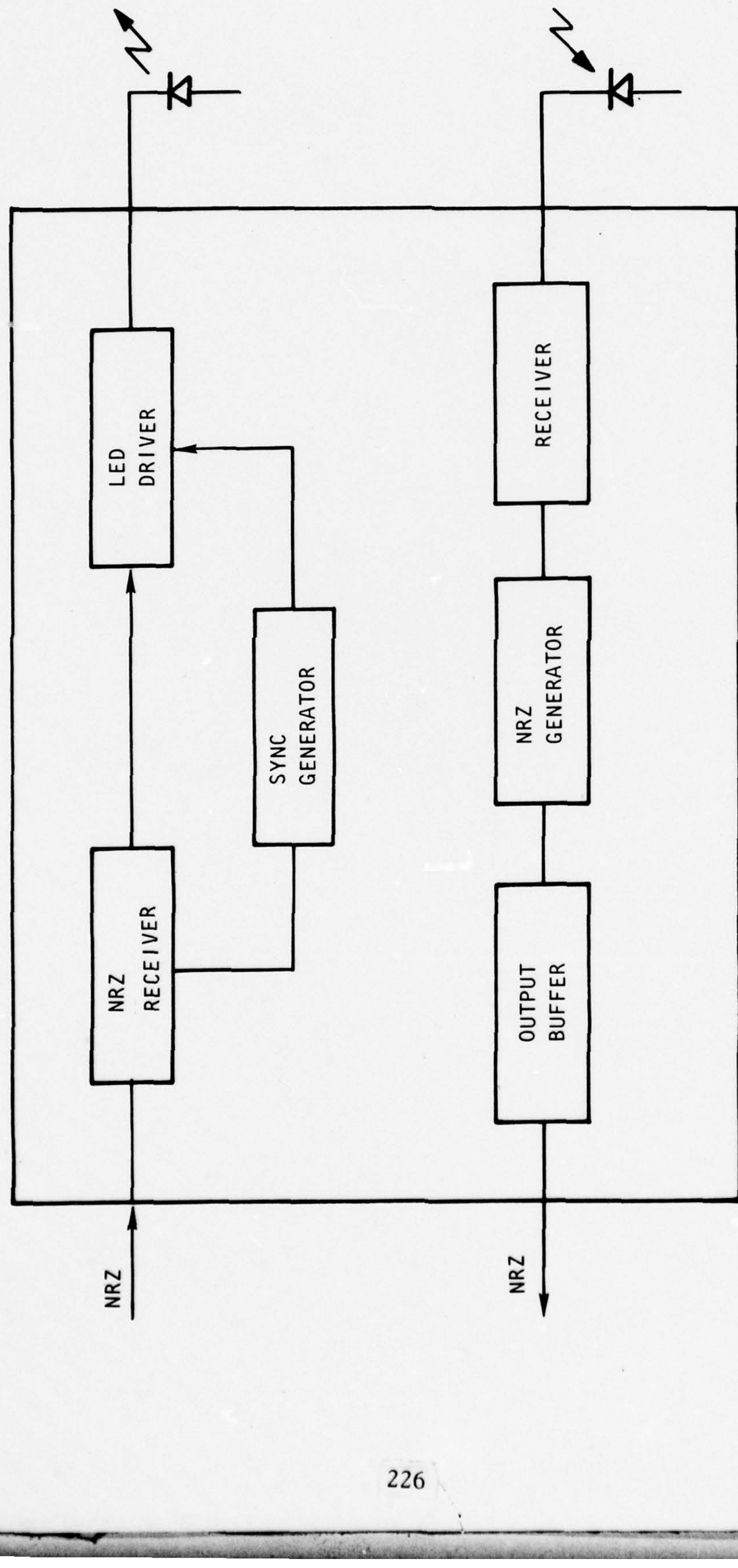


Figure D-1. Type B, single-channel FIM.

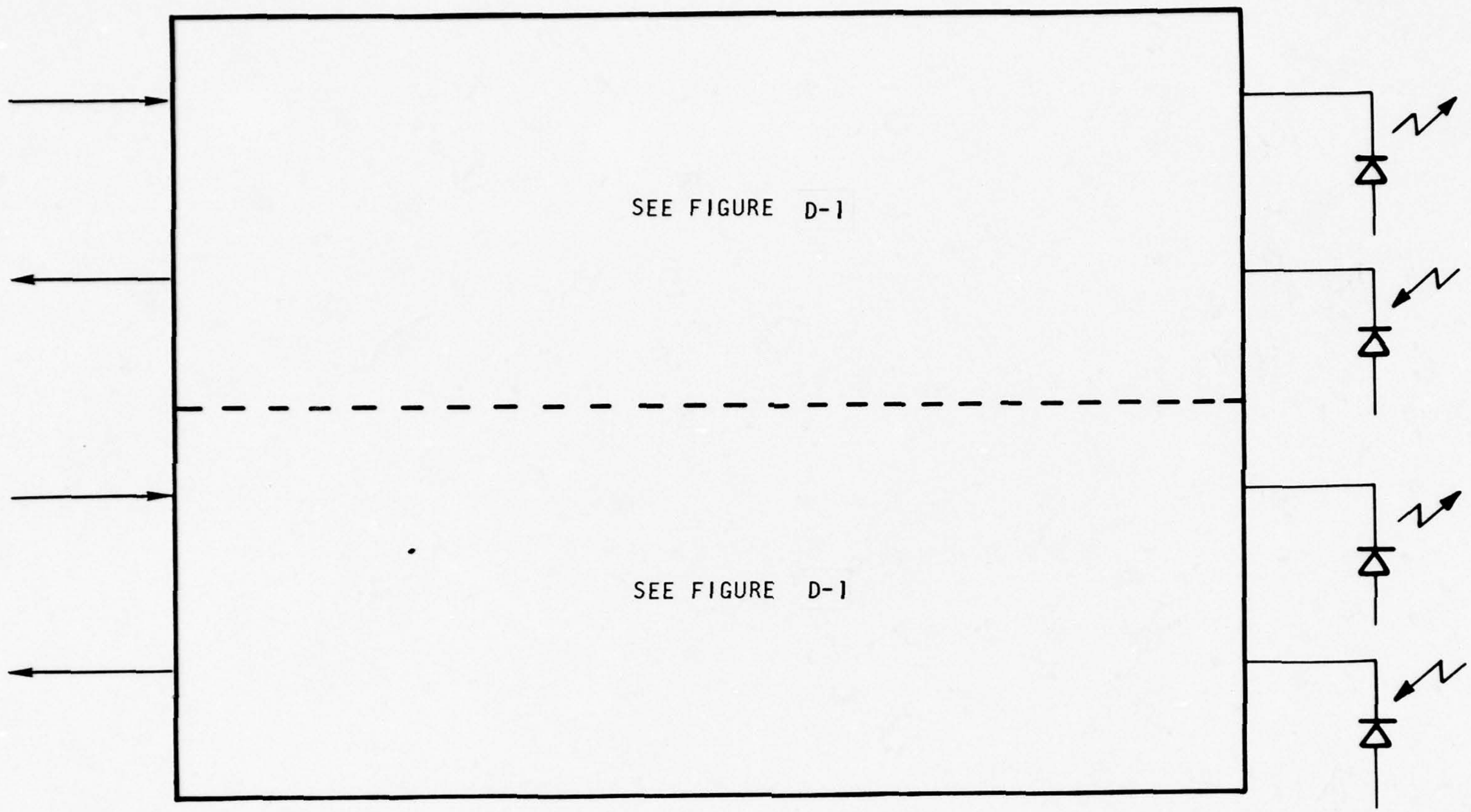


Figure D-2. Type A, dual-channel FIM.

b. Data Transmission:

(1) Form A. The FIM shall accept a command word from the controller and transmit a response word and up to 1024 data words.

(2) Form B. The FIM shall accept a command word from the controller and shall not respond with the response word or data words (an error in the command word received by the FIM).

3.3 Word Format. The word formats are defined in Figure D-3.

3.2.1 Command Word. The command word shall contain the information listed in Table D-1.

3.2.2 Response Word. The response word shall be generated by the FIM whenever a valid command word having an applicable address is received, except as noted in 3.1. For a valid data transmission, the response word shall be identical to the command word, except the sync shall be a data sync and bits 14 through 23 shall be a FIM status field (TBD). (Refer to Table D-2.)

For a nonvalid data transmission, the response word shall be identical to the command word, except the sync shall be a data sync, the validity bit shall be set to logic "1," and bits 14 through 23 shall be a FIM status field (TBD). The response word bit definitions are shown in Tables D-2 and D-3.

3.2.3 Data Word. The data word shall contain the information listed in Table D-4.

3.3 LRU Interface. The FIM's LRU interface shall consist of circuits to receive NRZ data from the LRU and to transmit NRZ data from the LRU and to transmit NRZ data to the LRU. Appropriate clock signals and control lines (TBD) are required to control the interface. (NOTE: Since this is a conceptual design for cost purposes, no attempt was made to identify the types of control signals, quantity, or timing of the signals except that there should not be more than five signals (one clock, two for input control, and two for output control).)

3.4 Fiber Optics Bus Interface. The FIM's optical I/O shall convert the NRZ data to an optical signal and optical signal to NRZ. The optical encoding scheme shall be (TBD). (NOTE: The FIM will transmit on a single fiber bundle all the required words, and receive data from another fiber bundle. A method of encoding and decoding the signal must be developed. The command sync and data sync can be encoded using pulse width modulation, or pulse position modulation, or frequency division modulation, or TBD; the information field can be likewise encoded. The only requirement is that the system can communicate and the decoder is compatible with the encoder.)

COMMAND WORD FORMAT

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
SYNC			S	V	S	S	MIM ADDRESS					T/R	DATA BLOCK/MODE — NO. OF WORDS										P

RESPONSE WORD FORMAT (VALID DATA TRANSMISSION)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
SYNC			S	V	S	S	MIM ADDRESS					T/R	STATUS										P

RESPONSE WORD FORMAT (INVALID DATA TRANSMISSION)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
SYNC			S	V*	S	S	MIM ADDRESS					T/R	STATUS										P

V* = SET TO LOGIC "1"

DATA WORD FORMAT

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
SYNC			S	V	S	S	DATA																P

V = VALIDITY S = SPARE P = PARITY

Figure D-3. Word format.

TABLE D-1. COMMAND WORD

Item	Bits	Definition
a	1 through 3	Command sync. (TBD).
b	4	Spare (S) bit - unused bit. Unused bits shall be set to logic "0."
c	5	Validity (V) bit. Logic "1": The command word is not usable due to controller's transmitting equipment having a fault condition as determined by self-test and/or monitoring components in the transmitting equipment. Logic "0": The command word meets acceptability criteria of transmitting unit as determined by its self-test and/or monitoring components.
d	6	Spare (S) bit - unused bit. Unused bits shall be set to logic "0."
e	7	Spare (S) bit - unused bit. Unused bits shall be set to logic "0."
f	8 through 12	Address bits. A five-bit code that identifies the FIM that shall respond to a given command word.
g	13	Transmit/receive (T/R) bit. Logic "1": Commands addressed FIM to transfer requested data. Logic "0": Commands addressed FIM to receive data.
h	14 through 23	Data block/mode - Number of words. This is a data field with dual use. (1). Bits 14 through 18 shall be used to identify the LRU data block starting memory location or command the LRU into a specific mode/operation and bits 19 through 23 shall be used to identify the number of data words to be transmitted/received. Code 0 0 0 0 1 shall be equal to one word and 1 1 1 1 1 shall be equal to 31. (2). Bits 14 through 23 shall identify the number of data words to be transmitted/received. Code 0 0 0 0 0 0 0 0 0 1 shall be equal to one and Code 1 1 1 1 1 1 1 1 1 1 shall be equal to 1023.

TABLE D-1. COMMAND WORD (CONCL)

Item	Bits	Definition
j	24	Parity (P) bit. This bit shall be set to a value so that the total number of ones in the word is odd.

3.5 Physical Properties.

3.5.1 Power Considerations. It is anticipated that the FIM shall use +5V (±5%) and ±15V (±5%) power supplied by the host at no more than 6 watts total for the type A FIM and 4 watts total for the type B FIM. The power figure includes the drive power for the LED.

3.5.2 Weight. The maximum weight for the FIM shall not exceed 0.6 pound for the type A and 0.4 pound for the type B.

3.5.3 Envelope. The maximum size for the FIM shall not exceed the following:

a. Type A: 2 x 3 x 0.5 in.

b. Type B: 2 x 2 x 0.5 in.

3.5.4 Mounting. (TBD)

3.6 Microelectronic Parts. MIL-M-38510 parts shall be used when available; otherwise, part screening in accordance with MIL-STD-883 shall be used.

4. QUALITY ASSURANCE

(TBD/TBR)

TABLE D-2. RESPONSE WORD (VALID DATA TRANSMISSION)

Item	Bits	Definition
a	1 through 3	Data sync. (TBD)
b	4	Spare. Definition per Table D-1.
c	5	Validity bit. Definition per Table D-1.
d	6	Spare. Definition per Table D-1.
e	7	Spare. Definition per Table D-1.
f	8 through 12	Address. Definition per Table D-1.
g	13	Transmit/receive. Definition per Table D-1.
i	14 through 23	Status Field. (TBD)
j	24	Parity. Definition per Table D-1.

TABLE D-3. RESPONSE WORD (INVALID DATA TRANSMISSION)

Item	Bits	Definition
a	1 through 3	Data sync. (TBD).
b	4	Spare (S) bit - unused bit. Unused bits shall be set to logic "0."
c	5	Validity (V) bit. Set to logic "1" only if one or more of the data words in the message contain a non-valid word sync, less than 21 bits, even parity, invalid data coding sequence, received data word with validity bit set to a logic "1", or if the number of words received is more or less than the number of words defined in the command word.
d	6	Spare (S) bits - unused bit. Unused bits shall be set to logic "0."
e	7	Spare (S) bits - unused bit. Unused bits shall be set to logic "0."
f	8 through 12	Address bits. Definition per Table D-1.
g	13	Transmit/receive (T/R) bit. Definition per Table D-1.
i	14 through 23	Status Field. (TBD).
j	24	Parity (P) bit. This bit shall be set so that the total number of ones in the word is odd.

TABLE D-4. DATA WORD

Item	Bits	Definition
a	1 through 3	Data sync. (TBD)
b	4	Spare (S) bit - unused bit. Unused bits shall be set to logic "0."
c	5	Validity (V) bit. Logic "1": Data word is not usable due to faulty transmission. (The data word shall be transmitted even if the validity bit is a logic "1." Logic "0": No data transmission fault(s) detected.
d	6	Spare bit - unused bit. Unused bit shall be set to logic "0."
e	7	Spare bit - unused bit. Unused bit shall be set to a logic "0."
f	8 through 23	Data. Information generated by LRU or controller. Information transmitted in binary, binary-coded decimal (BCD), discrete, or other required forms.
g	24	Parity (P) bit. This bit shall be set to a value so that the total number of ones in the word is odd.

Appendix E

TECHNICAL DESCRIPTION OF FOCAP FIBER OPTICS/MULTIPLEX INTERFACE MODULE (FOMIM) REPLACEMENT UNIT (NEW DESIGN)

1. SCOPE. This technical description establishes the requirements for the fiber optics study (FOCAP) interface circuitry to replace the existing multiplex interface module (MIM). The replacement unit shall be designated the fiber optics/multiplex interface module (FOMIM). The FOMIM shall be identical in every respect to the existing MIM except for the optical interface and data encoding/decoding.

2. APPLICABLE DOCUMENTS

a. Rockwell International

L409C2018

b. Others

(TBD/TBR)

3. REQUIREMENTS

3.1 Item Definition. The FOMIM shall meet the requirements of L409C2018 except for the optical interface. The FOMIM shall input and output data to the LRU with the interface established by L409C2018. The FOMIM shall transform the LRU data to signals compatible with the fiber optics data link and convert the optical data to signals compatible with the LRU interface established by L409C2018. (See Figure E-1.)

3.2 LRU Interface. The FOMIM LRU electrical interface shall conform to the requirements of L409C2018.

3.3 Fiber Optics Interface. The FOMIM optical I/O shall convert the LRU's parallel interface to a serial optical signal and vice versa. The optical encoding scheme shall be (TBD). (NOTE: The FOMIM will transmit on a single fiber bundle all the required signals. The FOMIM will receive data from another fiber bundle. A method of encoding and decoding the signal must be developed. The command sync and data sync can be encoded using pulsewidth modulation or pulse position modulation, or frequency division, or TBD; the information field can be likewise encoded. The only requirement on the bus

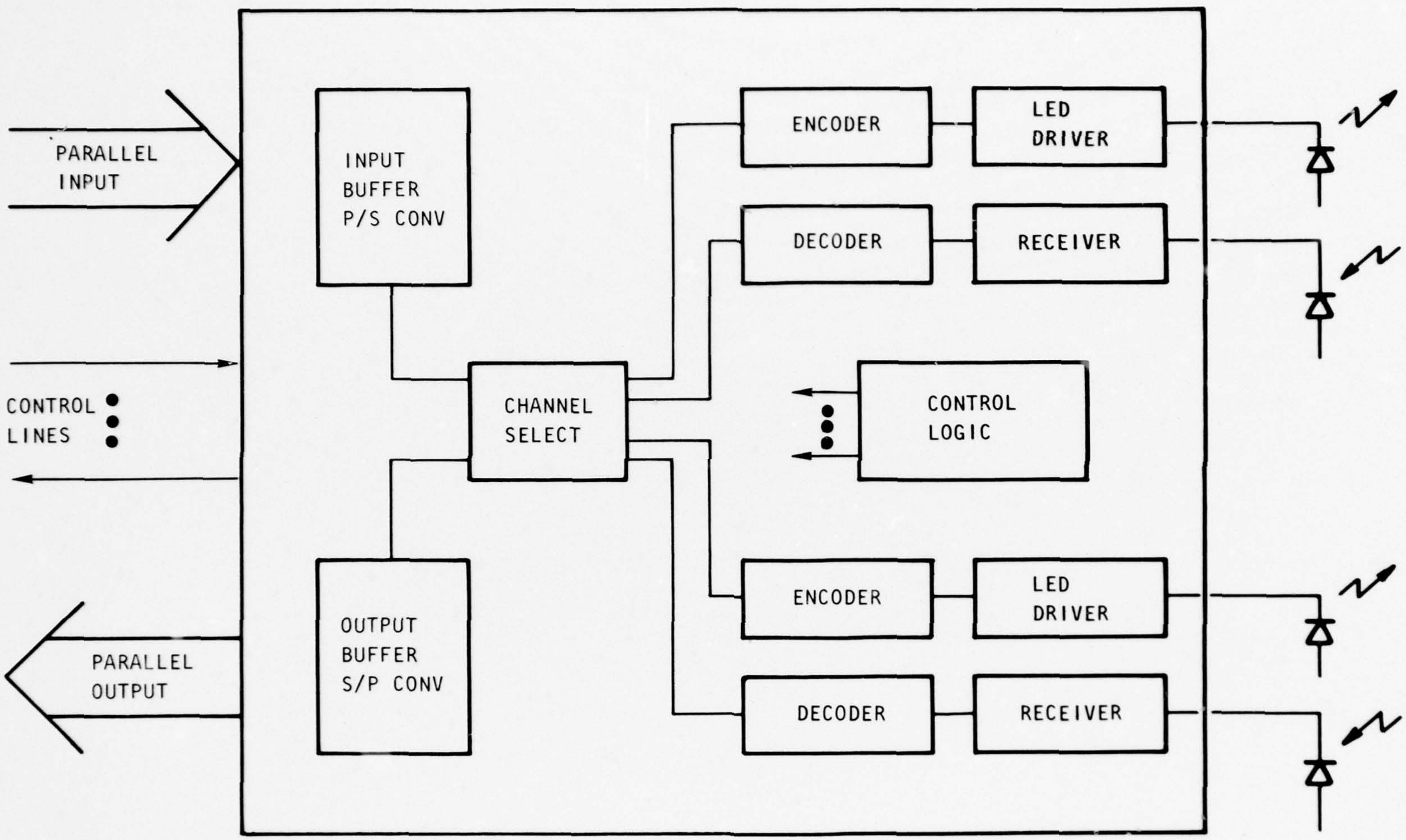


Figure E-1. FOMIM block diagram.

is that the system can communicate with similar units and that the decoder is compatible with the encoder.)

3.4 Physical Properties

3.4.1 Power Considerations. It is anticipated that the FOMIM shall use +5V (±5%) and ±15V (±5%) power supplied by the host at no more than 6 watts. The power figure includes the drive power for the LED.

3.4.2 Other Considerations. The requirements of L409C2018 shall govern other physical requirements for the FOMIM.

3.5 Microelectronic Parts. MIL-M-38510 parts shall be used when available; otherwise, parts screened in accordance with MIL-STD-883 shall be used.

4. QUALITY ASSURANCE

(TBD/TBR)

Appendix F

ACRONYMS AND ABBREVIATIONS

Acronym/ Abbreviation	Definition
A/C	Aircraft
a/w	Amperes/watt
ACQ	Acquisition
ACU	Avionics control unit
AFAL	Air Force Avionics Laboratory
AFCS	Automatic flight control subsystem
ALOFT	Airborne light optical fiber technology
AMUX	Avionics multiplex
AOA	Angle of attack
AP	Airborne printer
ATC	Air traffic control
AVL	Air vehicle limits
BCD	Binary-coded decimal
BER	Bit error rate
CADC	Central air data computer
CADS	Central air data system
CCD	CITS control and display
CDR/CPI	Crash data recorder/crash position indicator
CER	Cost estimating relationship
CFC	Current feedback coupling
CFY	Corporate fiscal year
CITS	Central integrated test system
CMOS/SOS	Complementary metal oxide silicon/silicon on sapphire
CONV	Converter
DATI	Data in strobe
DATO	Data out strobe
DAU	Data acquisition unit
db/km	Decibels per kilometer
dbm	Decibel milliwatt
DDS	Dope deposited silicon
DMS	Defensive management system
DSC	Defensive supply center
DSG	Defensive subsystem group
DS-3	Digital Serial-3
DTLCC	Data transfer life cycle cost

Acronym/ Abbreviation	Definition
ECL	Emitter coupled logic
EMI	Electromagnetic interference
EMP	Electromagnetic pulse
EMUX	Electrical multiplex
engrg	Engineering
EMIC	Electromagnetic interference and compatibility
EOAU	Electro-optical adapter unit
EVS	Electro-optical viewing system
FCOST	Fighter cost
FDC	Flight director computer
FIM	Fiber interface module
FLIR	Forward-looking infrared
FLR	Forward-looking radar
FOCAP	Fiber optics cost analysis program
FISC	Flight instruments signal converter
FOMIM	Fiber optic multiplex interface modules
FY	Fiscal year
G&A	General and administrative cost
GFE	Government furnished equipment
GMCPS	Ground maintenance circuit Protection System
GNACU	Guidance and navigation avionics control unit
GSS	Gyro stabilization system
HF	High frequency
I/O	Input/output
IA	Interface adaptation
IC	Integrated circuit
IFF	Identification, friend or foe
ILS	Instrument landing system
IMU	Inertial measuring units
INS	Inertial navigation system
IEU	Inertial electronic unit
instl	Installation
IR&D	Independent research and development
kva	Kilovolt-ampere
LAD	Los Angeles Division
LCC	Life cycle cost
LN_2	Liquid nitrogen

Acronym/ Abbreviation	Definition
LRU	Line replaceable unit
LSA	Large strategic aircraft
LSI	Large scale integration (integrated circuit)
LED	Light emitting diode
M&TC	Mission and traffic control
M	Million
max	maximum
mb/sec	Megabit/second
MDR	Maintenance demand rate
MFCS	Manual flight control subsystem
MIM	Multiplex interface modules
MMH/FH	Maintenance/man-hours per flight hour
MPC	Material procurement cost
MTBF	Mean time between failures
mtl	Material
MTTR	Mean time to repair/replace
MUX	Multiplex
N/WDS	Navigation/weapons delivery system
NAVS/RADAR	Navigation/radar
NOSC	Naval Ocean System Center
NRZ	Nonreturn-to-zero
NWC	Naval Weapons Center
O&S	Operations and support
OSE	Operational support equipment
P/S	Parallel-to-serial
P	Parity
PACU	Preprocessor avionics control unit
PCFS	Plastic clad, fused silica
PCM	Production cost model
PDE	Procurement direct expense
PVC	Polyvinylchloride
PWM	Pulse width modulated
Q&RA	Quality and reliability assurance
RDT&E	Research, development, test, and evaluation
RFS/ECMS	Radiofrequency surveillance/electronic countermeasures
RGA	Rotation go-around

Acronym/ Abbreviation	Definition
S/N	Signal-to-noise (ratio)
SCAS	Stability and control augmentation system
SDAU	Super data acquisition unit (same as data terminal)
SEAT	System evaluation and test
Si	Silicon
S	Spare
SMCF	Structural mode control fin
SMCS	Structural mode control subsystem
SMS	Stores management system
SOTA	State-of-the art
T/W	Thrust-to-weight ratio
T/R	Transmit/receive
TBD	To be determined
TBR	To be recommended
TF/TA	Terrain following/terrain avoidance
TREE	Transient radiation effects on electronics
TTL	Transistor-transistor logic
UE	Unit equipment
V	Validity
VS/PEP	Vehicle sizing and performance evaluation program
VSD	Vertical situation display
WPAFB	Wright Patterson Air Force Base
WBS	Work breakdown structure

Appendix F

REFERENCES

1. Rockwell International, B-1 Division, "Fiber Optics Cost Analysis Program (FOCAP) Interim Report," Report NA-76-674, Volumes I and II, 23 December 1976

2. Rockwell International, B-1 Division, "Potential Application of Fiber Optics Data Transfer to B-1 DSG," Report NA-76-305, 30 September 1976

3. Rockwell International, B-1 Division, "Defensive Subsystem Group Video/Non-RF and Digital/Analog Transmission Line Data," Report TFD-75-1370, Revision B, 2 September 1976

4. Rockwell International, B-1 Division, "Initial Screening of B-1 Systems to Fiber Optics Implementation," Report TFD-76-1452, 30 November 1976

5. Baird, J. R., "Optoelectronic Aspects of Avionic Systems II," AFAL-TR-75-45, Spectronics, Inc, May 1975

6. Milman, J., and Taub, H., Pulse, Digital, and Switching Waveforms, McGraw-Hill Book Company, New York, 1965

7. Baird, J. R., and Stewart, L. L., "Optoelectronic Data Bus," AFAL-TR-73-271, October 1973

8. Rockwell International, B-1 Division, "Fiber Optics Interface Adapter Unit for B-1 Defensive Subsystem Group," Report NA-76-674, 25 September 1976

9. United States Air Force, Logistics Command, "Cost Analysis AFLC Increase Reliability of Operational Systems (IROS) Program," AFLCM 66-18, Chapter 15, 27 September 1974

10. National Aeronautics and Space Administration, "Study of Cost Estimation of Research and Development Programs," NASA CR-114368, 21 September 1971

11. Rockwell International, B-1 Division, "CFY 1976 Improvements to Production Cost Model (PCM)," Report TFD-76-1256, 17 March 1977

12. Rockwell International, B-1 Division, CFY 1976 Improvements to FCOST Life Cycle Cost Model," Report TFD-76-1257, 24 February 1977

13. Rockwell International, Los Angeles Aircraft Division, "User's Manual for Data Transfer Life Cycle Cost (DTLCC) Model," Report NA-77-587, 27 May 1977

14. Rockwell International, B-1 Division, "FOCAP-RDT&E Man-hours for Fiber Optics in the B-1 DSG," Report TFD-77-288, 21 March 1977

15. United States Air Force, Headquarters USAF, "USAF Cost and Planning Factors," AFR 173-10, Volume I, 6 February 1975

16. Rockwell International, Los Angeles Aircraft Division, "Fiber Optic Cost Analysis Program; B-1 Subsystems Life Cycle Cost Results," NA-77-779, 19 July 1977

17. Naval Electronics Laboratory Center, "A-7 Life Cycle Cost and Measures of Effectiveness Models," NELC/TR 1982, 1 March 1976

18. Rockwell International, B-1 Division, "Electromagnetic Interference and Compatibility," NA-72-24, 29 January 1976